H. O. No. 226

HANDBOOK OF MAGNETIC COMPASS ADJUSTMENT and COMPENSATION

SECOND EDITION

SPENCER and KUCERA

UNITED STATES NAVY DEPARTMENT
HYDROGRAPHIC OFFICE

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INTRODUCTION

This handbook of magnetic compass correction, for both normal and degaussed conditions, has been prepared in order to present all pertinent information regarding the practical procedures of adjustment and compensation in one text. As such, it deals with the basic principles of compass deviations and their correction, and not with the details of particular compass equipment. However, since no standard texts have been prepared on degaussing and its effects on the compass, this text not only includes the principles of degaussing compensations, but also the details of compass compensating coil equipments and their electrical characteristics.

Although this text is presented as a systematic treatise on compass adjustment and compensation, ship's personnel who are inexperienced with compass correction will find sufficient information in **chapters I and X** to eliminate compass errors satisfactorily without intensive study of the entire text. Reference should also be made to **figure 19** for condensed information regarding the various compass errors and their correction.

In this handbook the term *compass adjustment* refers to any change of permanent magnet or soft iron correctors whereby normal compass errors are reduced. The term *compass compensation* refers to any change in the currents supplied to the compass compensating coils whereby the errors due to degaussing are reduced. These terms differ from those used in previous compass publications but are in accordance with recently approved Navy nomenclature established so as to distinguish between the two correction procedures.

This text is the outgrowth of lecture notes prepared by the authors while presenting courses of instruction in adjustment and compensation at the Magnetic Compass Demonstration Station, Naval Operating Base, Norfolk, Va. These courses were designed primarily for the Specialist Officer Training Program, and were also utilized by various other training activities in and around Norfolk. A basic, simplified *check-off list* was used as the nucleus of these courses, and the lecture material was so designed as to amplify this *check-off list*. In view of the obvious need for a practical handbook for Navy personnel, both at shore stations and at sea, it was decided to expand the lecture material into such a text, based on personal experience with compass adjustment, compensation, and compass coil design.

Special credit is due Commander Myron J. Walker, U. S. N. (Ret.), under whose direction the above work was accomplished, for his encouragement and assistance in the preparation of this text, and for his efforts in bringing it to the attention of the Navy Department by whom it was subsequently approved. Acknowledgement is due the compass officers and technicians of the Bureau of Ships and the Hydrographic Office who were very cooperative and helpful in reviewing the subject material. The authors are also grateful for the helpful suggestions made by the compass adjustors of the various naval districts.

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Part I.—MAGNETIC ADJUSTMENT

CHAPTER I. PROCEDURES FOR MAGNETIC COMPASS ADJUSTMENT (CHECK-OFF LIST)

NOTE.—If the magnetic adjustment necessitates (*a*) movement of degaussing compensating coils, or (*b*) a change of Flinders bar length, the coil compensation must be checked. Refer to ch. X.

1. **A. Dockside tests and adjustments.**

   1. Physical checks on the compass and binnacle.
      - (*a*) Remove any bubbles in compass bowl (art. 72).
      - (*b*) Test for moment and sensibility of compass needles (art. 73).
      - (*c*) Remove any slack in gimbal arrangement. See (*g*) below.
      - (*d*) Magnetization check of spheres and Flinders bar (art. 74).
      - (*e*) Alignment of compass with fore-and-aft line of ship (art. 75).
      - (*f*) Alignment of magnet trays in binnacle.
      - (*g*) Alignment of heeling magnet tube under pivot point of compass.
      - (*h*) See that corrector magnets are available.
   2. Physical checks of gyro, azimuth circle, and peloruses.
      - (*a*) Alignment of all gyro repeater peloruses or dial peloruses with fore-and-aft line of ship (art. 75).
      - (*b*) Synchronize gyro repeaters with master gyro.
      - (*c*) Make sure azimuth circle and peloruses are in good operating condition.
   3. Necessary data.
      - (*a*) Past history or log data which might establish length of Flinders bar (arts. 77 and 96).
      - (*b*) Local apparent time and watch setting (arts. 63, 64, and 65).
      - (*c*) Azimuths for given date and latitude (ch. VI).
      - (*d*) Ranges or distant objects in vicinity (local charts).
      - (*e*) Correct variation (local charts).
      - (*f*) Degaussing coil current settings for swing for residual deviations after adjustment and compensation (Ship's degaussing folder).

4. Precautions.
   (*a*) Determine transient deviations of compass from gyro repeaters, doors, guns, etc. (ch. IX).
   (*b*) Secure all effective magnetic gear in normal sea-going position before beginning adjustments.
   (*c*) Make sure degaussing coils are secured before beginning adjustments. Use reversal sequence, if necessary (art. 128).
   (*d*) Whenever possible, correctors should be placed symmetrically with respect to the compass (arts. 32 and 102).
5. Adjustments.
   (a) Place the Flinders bar according to best available information (arts. 77, 97, and 98).
   (b) Set spheres at mid-position, or as indicated by last deviation table.
   (c) Adjust heeling magnet, using balanced dip needle (ch. XV).
   (d) Adjust degaussing compass compensating coil currents (ch. X).

2. B. **Adjustments at sea.**—(*These adjustments are made with the ship on an even keel and after steadying on each heading. When using the gyro, swing from heading to heading slowly and check gyro error by sun's azimuth or ranges on each heading* (*art. 48*). *Be sure gyro is set for the mean speed and latitude of the vessel. Note all precautions in section A–4 above. "Jig King" international code signal should be flown to indicate such work is in progress. Chapter V discusses methods for placing the ship on desired headings*).

1. Come to a cardinal magnetic heading, e. g. *east* (090°). Insert fore-and-aft *B* magnets, or move the existing *B* magnets, in such manner as to remove all deviation.
2. Come to a *south* (180°) magnetic heading. Insert athwartship *C* magnets, or move the existing *C* magnets, in such manner as to remove all deviation.
3. Come to a *west* (270°) magnitic heading. Correct half of any observed deviation by moving the *B* magnets.
4. Come to a *north* (000°) magnetic heading. Correct half of any observed deviation by moving the *C* magnets.

(*The cardinal heading adjustments should now be complete*).

5. Come to any intercardinal magnetic heading, e. g. *northeast* (045°). Correct any observed deviation by moving the spheres in or out.
6. Come to the next intercardinal magnetic heading, e. g., *southeast* (135°). Correct half of any observed deviation by moving the spheres.

The intercardinal heading adjustments should now be complete, although more accurate results might be obtained by correcting the D error determined from the deviations on all four intercardinal headings, as discussed in art. 38.

7. Readjust the heeling magnet so as to remove oscillations of compass card, with ship under rolling conditions on a north and south heading (ch. XV).
8. Secure all correctors before swinging for residual deviations.
9. Swing for residual *undegaussed deviations* on as many headings as desired, although the eight cardinal and intercardinal headings should be sufficient.
10. Should there still be any large deviations, the procedure under "Adjustments at Sea" will have to be repeated. If the resulting deviation curve is still unsatisfactory, analyze it to determine the necessary corrections (ch. IV and art. 87).
11. Record deviations and the details of corrector positions on standard Navy Form NBS 1104 or 1105, and in the *Compass Record Book*, NBS 1101 (arts. 89 and 132).
12. Refine degaussing compass compensating coil adjustments (ch. X).
13. Swing for residual *degaussed deviations* with the degaussing circuits properly energized (ch. X).
14. Record deviations for degaussed conditions (art. 126).

3. The above *check-off list* describes a simplified method of adjusting compasses, designed to serve as a simple workable outline for the novice who chooses to follow a step-by-step procedure. The "Dockside Tests and Adjustments" are essential as a foundation for the "Adjustments at Sea," and if neglected may lead to spurious results or needless repetition of the procedures at sea. Hence, it is strongly recommended that careful consideration be given these dockside checks prior to making the final adjustment so as to allow time to repair or replace faulty compasses, anneal or replace magnetized

spheres or Flinder bar, realign binnacle, move gyro repeater if it is affecting the compass, or to make any other necessary preliminary repairs. It is further stressed that expeditious compass adjustment is dependent upon the application of the various correctors in a logical sequence so as to achieve the final adjustment with a minimum number of steps. This sequence is incorporated in the above check-off list and better results will be obtained if it is adhered to closely. Figure 19 presents the various compass errors and their correction in condensed form, and the table in figure 1 will further clarify the mechanics of placing the corrector magnets, spheres, and Flinders bar. Chapter VII discusses the more efficient and scientific methods of adjusting compasses, in addition to a more elaborate treatment of the items mentioned in the *check-off list*. Frequent, careful observations should be made to determine the constancy of deviations, and results should be systematically recorded. Significant changes in deviation will indicate the need for readjustment.

Mechanics of magnetic compass adjustment

Fore-and-aft and athwartship magnets			Quadrantal spheres			Flinders bar		
Deviation → **Magnets** ↓	Easterly on east *and* westerly on west. (+B error)	Westerly on east *and* easterly on west. (−B error)	**Deviation** → **Spheres** ↓	E. on NE, W. on SE, E. on SW, *and* W. on NW. (+D error)	W. on NE, E. on SE, W. on SW, *and* E. on NW. (−D error)	**Deviation change with latitude change** → **Bar** ↓	E. on E. *and* W. on W. when sailing toward equator from north latitude or away from equator to south latitude.	W. on E. *and* E. on W. when sailing toward equator from north latitude or away from equator to south latitude.
No fore and aft magnets in binnacle.	Place magnets red forward.	Place magnets red aft.	No spheres on binnacle.	Place spheres athwartship.	Place spheres fore and aft.	No bar in holder.	Place required amount of bar forward.	Place required amount of bar aft.
Fore and aft magnets red forward.	Raise magnets.	Lower magnets.	Spheres at athwartship position.	Move spheres toward compass or use larger spheres	Move spheres outwards or remove.	Bar forward of binnacle.	Increase amount of bar forward.	Decrease amount of bar forward.
Fore and aft magnets red aft.	Lower magnets.	Raise magnets.	Spheres at fore and aft position.	Move spheres outward or remove.	Move spheres toward compass or use larger spheres	Bar aft of binnacle.	Decrease amount of bar aft.	Increase amount of bar aft.
Deviation → **Magnets** ↓	Easterly on north *and* westerly on south. (+C error)	Westerly on north *and* easterly on south. (−C error)	**Deviation** → **Spheres** ↓	E. on N, W. on E, E. on S, *and* W. on W. (+E error)	W. on N, E. on E, W. on S, *and* E. on W. (−E error)	↑ **Bar** **Deviation change with latitude change** →	W. on E. *and* E. on W. sailing toward equator from south latitude or away from equator to north latitude.	E. on E. *and* W. on W. when sailing toward equator from south latitude or away from equator to north latitude.
No athwartship magnets in binnacle.	Place athwartship magnets red starboard.	Place athwartship magnets red port.	No spheres on binnacle.	Place spheres at port forward and starboard aft intercardinal positions.	Place spheres at starboard forward and port aft intercardinal positions.	Heeling magnet (Adjust with changes in magnetic latitude)		
Athwartship magnets red starboard.	Raise magnets.	Lower magnets.	Spheres at athwartship position.	Slew spheres clockwise through required angle.	Slew spheres counter-clockwise through required angle.	If compass north is attracted to high side of ship when rolling, *raise* the heeling magnet if red end is up and *lower* the heeling magnet if blue end is up.		
Athwartship magnets red port.	Lower magnets.	Raise magnets.	Spheres at fore and aft position.	Slew spheres counter-clockwise through required angle.	Slew spheres clockwise through required angle.	If compass north is attracted to low side of ship when rolling, *lower* the heeling magnet if red end is up and *raise* the heeling magnet if blue end is up.		

FIGURE 1.

CHAPTER II. MAGNETISM

4. The magnetic compass.—The principle of the present day magnetic compass is in no way different from that of the compass used by the ancients. It consists of a *magnetized needle*, or *array of needles*, pivoted so that it will rotate in a horizontal plane. The superiority of the present day compass results from a better knowledge of the laws of magnetism which govern the behavior of the compass, and from greater precision in construction.

5. Magnetism.—Any piece of metal on becoming *magnetized*, that is, acquiring the property of attracting small particles of iron or steel, will assume *regions of concentrated magnetism*, called *poles*. Any such magnet will have at least two poles, of unlike polarity. *Magnetic lines of force* (flux) connect one pole of such a magnet with the other pole as indicated in figure 2. The number of such lines per unit area represent the *intensity* of the so-called *magnetic field* in that area.

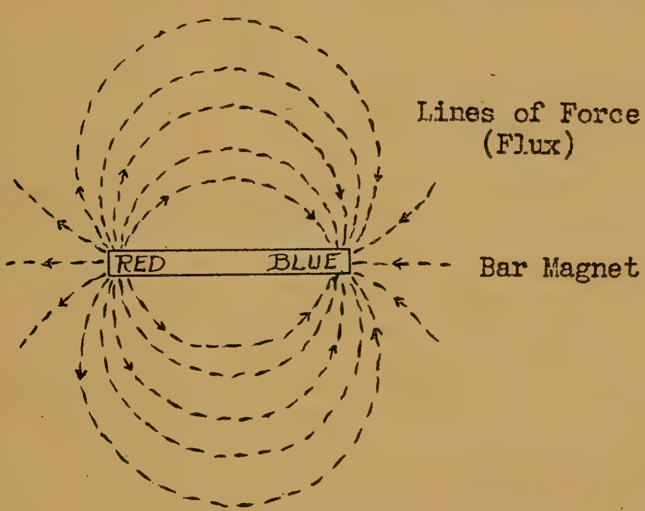


FIGURE 2.—Lines of magnetic force about a magnet.

If two such magnetized bars or magnets are placed side by side, *the like poles will repel each other and the unlike poles will attract each other.*

6. Magnetism is in general of two types, *permanent* and *induced*. A bar having permanent magnetism will retain its magnetism when it is removed from the magnetizing field. A bar having induced magnetism will lose its magnetism when removed from the magnetizing field. Whether or not a bar will retain its magnetism on removal from the magnetizing field will depend on the strength of that field, the degree of hardness of the iron (retentivity), and also upon the amount of physical stress applied to the bar while in the magnetizing field. The harder the iron the more permanent will be the magnetism acquired.

7. **Terrestrial magnetism.**—The accepted theory of terrestrial magnetism considers the earth as a huge magnet surrounded by lines of magnetic force which connect its two *magnetic poles.* These magnetic poles are near, but not coincidental, with the *geographic poles* of the earth. Since the *north seeking end* of a compass needle is conventionally called a *red pole*, *north pole*, or *positive pole*, it must therefore be attracted to a pole of opposite polarity, or to a *blue pole*, *south pole*, or *negative pole.* The magnetic pole near the north geographic pole is therefore a blue pole, south pole, or negative pole; and the magnetic pole near the south geographic pole is a red pole, north pole, or positive pole.

8. Figure 3 illustrates the earth and its surrounding magnetic field. The flux lines enter the surface of the earth at different angles to the horizontal, at different *magnetic latitudes.* This angle is called the *angle of magnetic dip*, θ, and increases from zero, at the magnetic equator, to 90° at the magnetic poles. The total magnetic field is generally considered as having two components, namely H, the horizontal component, and Z, the vertical component. These components will change when the angle θ changes such that H is *maximum* at the magnetic equator and *decreases* in the direction of either pole, and Z is *zero* at the magnetic equator and *increases* in the direction of either pole. The values of H and Z may be found on U. S. Navy Hydrographic Office charts H. O. 1701 and H. O. 1702 (figs. 4 and 5).

9. Inasmuch as the magnetic poles of the earth are not coincidental with the geographic poles, it is evident that a compass needle in line with the earth's magnetic field will not indicate *true north*, but *magnetic north.* The angular difference between the *true meridian* (great circle connecting the geographic poles) and the *magnetic meridian* (direction of the lines of magnetic flux) is called *variation.* This variation has different values at different locations on the earth. These variation values may be found on U. S. Navy Hydrographic Office Chart H. O. 2406 (fig. 6) and, more exactly for each locality, on the *compass rose* of navigational charts. The variation for most given areas undergoes an *annual change*, the amount of which is also noted on all charts.

10. Ship's magnetism.—A ship while in the process of being constructed will acquire magnetism of a permanent nature under the extensive hammering it receives in the earth's magnetic field. After launching, the ship will lose some of this original magnetism as a result of vibration, pounding, etc., in varying magnetic fields, and will eventually reach a more or less stable magnetic condition. This magnetism which remains is the so-called *permanent magnetism* of the ship.

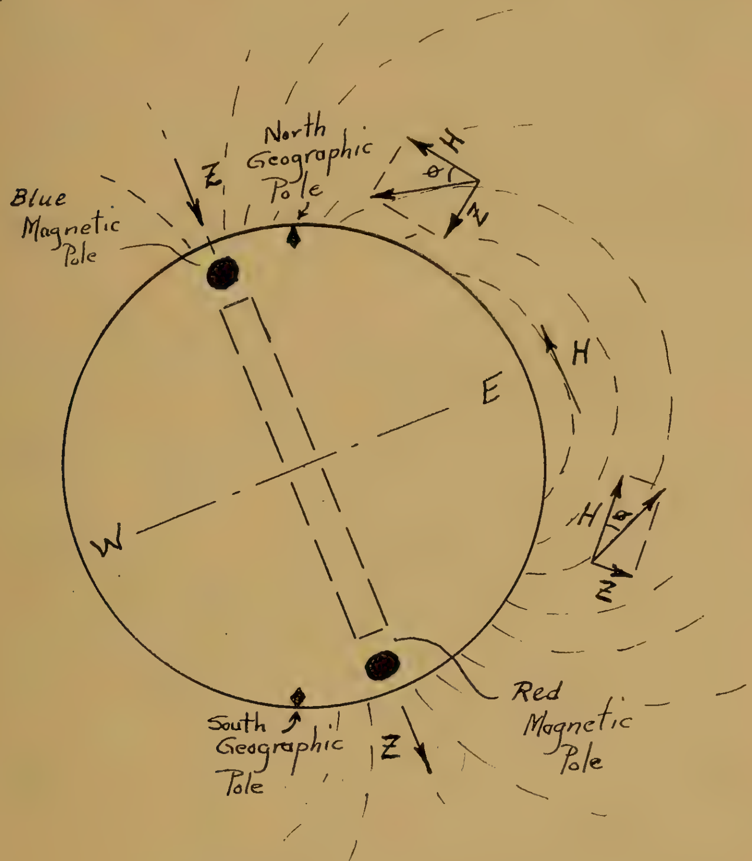


FIGURE 3.—Terrestrial magnetism.

11. The fact that a ship has permanent magnetism does not, of course, mean that it cannot also acquire *induced magnetism* when placed in a magnetic field such as the earth's field. The amount of magnetism induced in any given piece of soft iron is dependent upon the field intensity, the alignment of the soft iron in that field, and the physical properties and dimensions of the iron. This induced magnetism may add to or subtract from the permanent magnetism

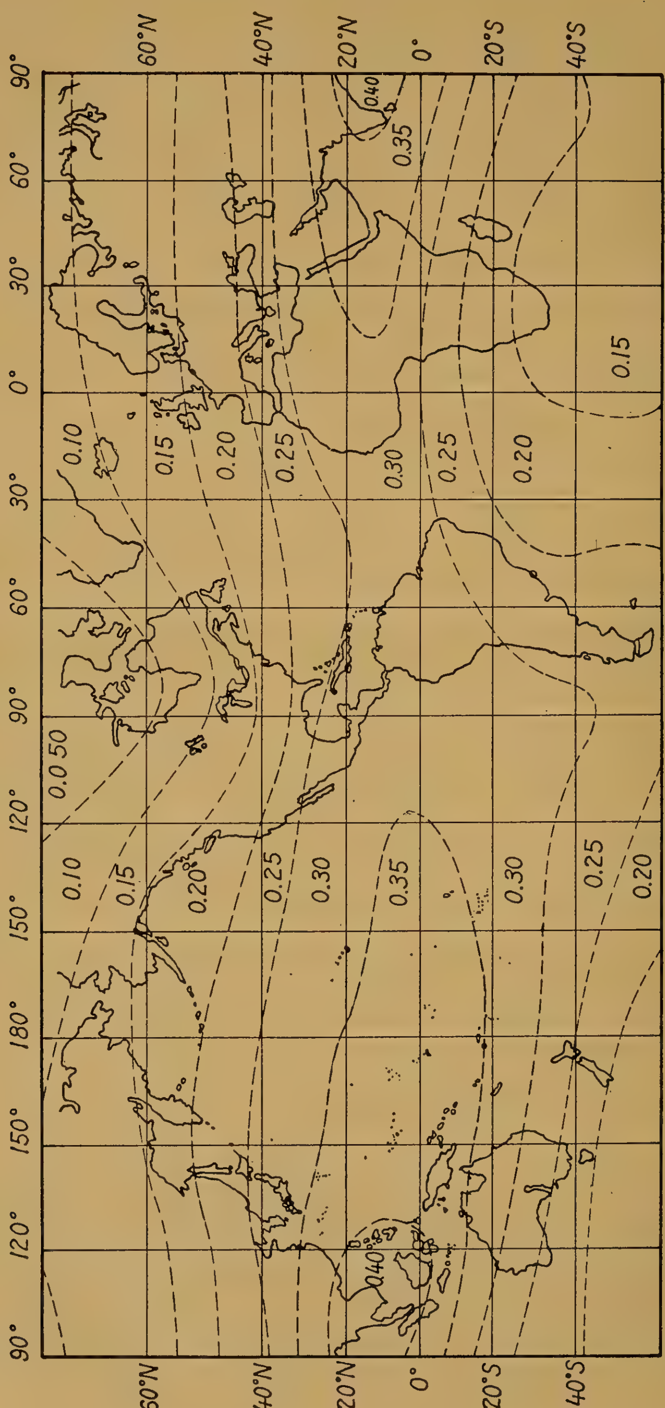


FIGURE 4.—Earth's horizontal magnetic field zones—H zones in gauss. (Adapted from H. O. Chart 1701.)

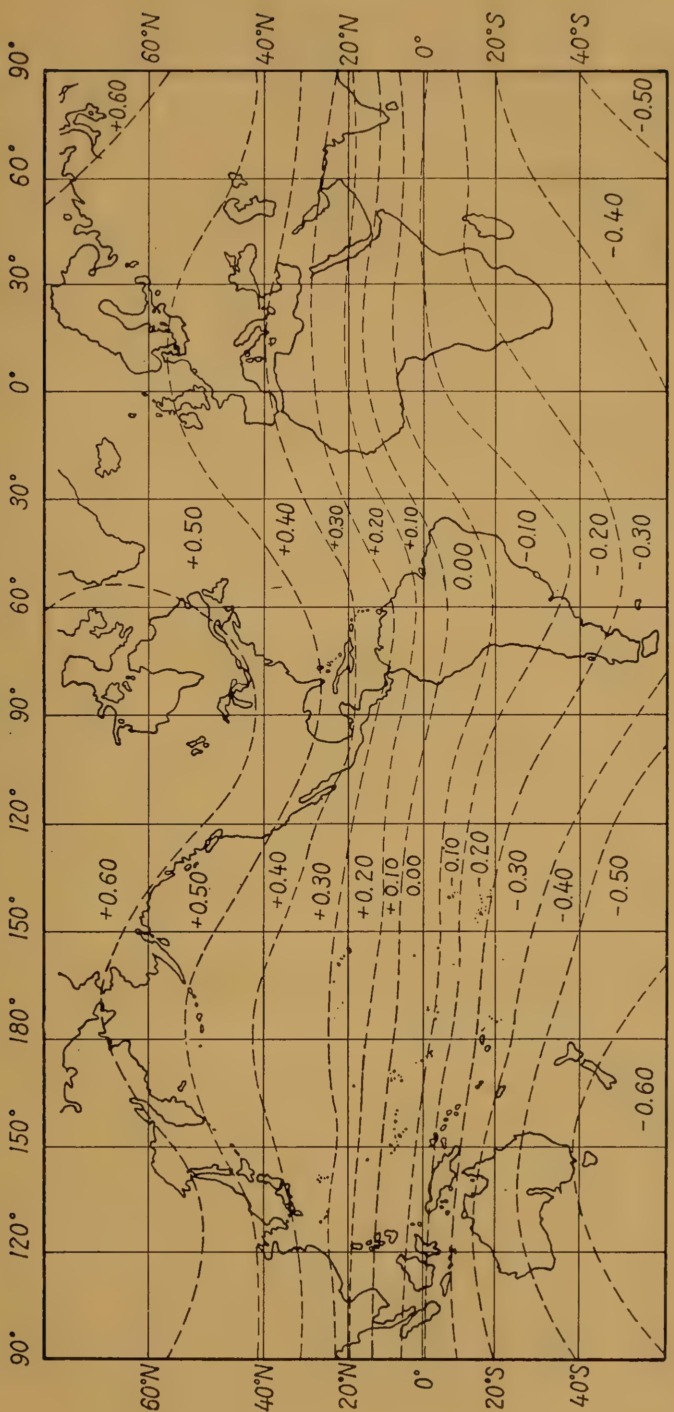


FIGURE 5.—Earth's vertical magnetic field zones—Z zones in gauss. (Adapted from H. O. Chart 1702.)

already present in the ship, depending on how the ship is aligned in the magnetic field. The softer the iron the more readily it will be induced by the earth's magnetic field, and the more readily it will give up its magnetism when removed from that field.

12. The magnetism in the various structures of a ship which tends to change as a result of cruising, vibration, or aging, but does not alter immediately so as to be properly termed induced magnetism, is called *subpermanent magnetism.* This magnetism at any instant is recognized as part of the ship's permanent magnetism, and consequently must be corrected as such by means of *permanent magnet correctors.* This subpermanent magnetism is the principal cause of *deviation changes* on a magnetic compass. Subsequent reference to permanent magnetism in this text will refer to the apparent permanent magnetism which includes the existing permanent and subpermanent magnetism at any given instant.

13. A ship, then, has a combination of *permanent*, *subpermanent*, and *induced magnetism*, since its metal structures are of *varying degrees of hardness.* Thus, the apparent permanent magnetic condition of the ship is subject to change from deperming, excessive shocks, welding, vibration, etc.; and the induced magnetism of the ship will vary with the strength of the earth's magnetic field at different magnetic latitudes, and with the alignment of the ship in that field.

14. Resultant induced magnetism from earth's magnetic field.—The above discussion of induced magnetism and terrestrial magnetism leads to the following facts. A long thin rod of soft iron in a plane parallel to the earth's horizontal magnetic field, H, will have a red (north) pole induced in the end toward the north geographic pole and a blue (south) pole induced in the end toward the south geographic pole. This same rod in a horizontal plane but at right angles to the horizontal earth's field would have no magnetism induced in it, because its alignment in the magnetic field is such that there will be no tendency toward linear magnetization and the rod is of negligible cross section. Should the rod be aligned in some horizontal direction between those headings which create maximum and zero induction, it would be induced by an amount which is a function of the angle of alignment. If a similar rod is placed in a vertical position in northern latitudes so as to be aligned with the vertical earth's field, Z, it will have a blue (south) pole induced at the upper end and a red (north) pole induced at the lower end. These polarities of vertical induced magnetization will be reversed in southern latitudes.

The amount of horizontal or vertical induction in such rods, or in ships whose construction is equivalent to combinations of such rods, will vary with the intensity of H and Z, heading, and heel of the ship.

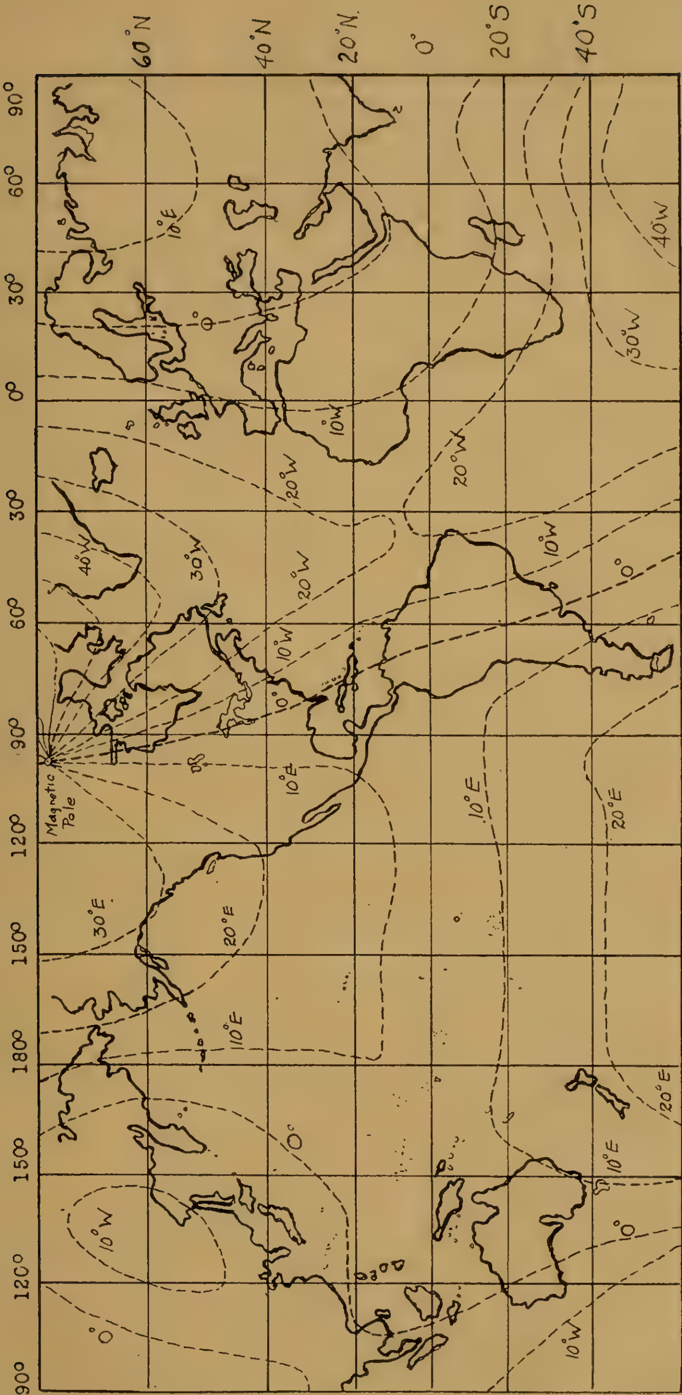


FIGURE 6.—Earth's magnetic variation chart (adapted from H. O. 2406).

CHAPTER III. THEORY OF MAGNETIC COMPASS ADJUSTMENT

15. Magnetic adjustment.—The magnetic compass when used on a steel ship must be so corrected for the ship's magnetic conditions that its operation would be the same as if it were on a nonmagnetic ship. Ship's magnetic conditions create *deviations* of the magnetic compass, as well as *sectors of sluggishness and unsteadiness. Deviation* is defined as deflection of the card (needles) to the right or left of the magnetic meridian. *Adjustment* of the compass is the arranging of *magnet and soft iron correctors* about the binnacle so that their effects are equal and opposite to the effects of the magnetic material in the ship, thus reducing the deviations and eliminating the sectors of sluggishness and unsteadiness.

The magnetic conditions in a ship which affect a magnetic compass are *permanent magnetism* and *induced magnetism*, as discussed in chapter II.

16. Permanent magnetism and its effects on the compass.—The *total permanent magnetic field effect at the compass* may be broken into *three components*, mutually 90° apart, as shown in figure 7.

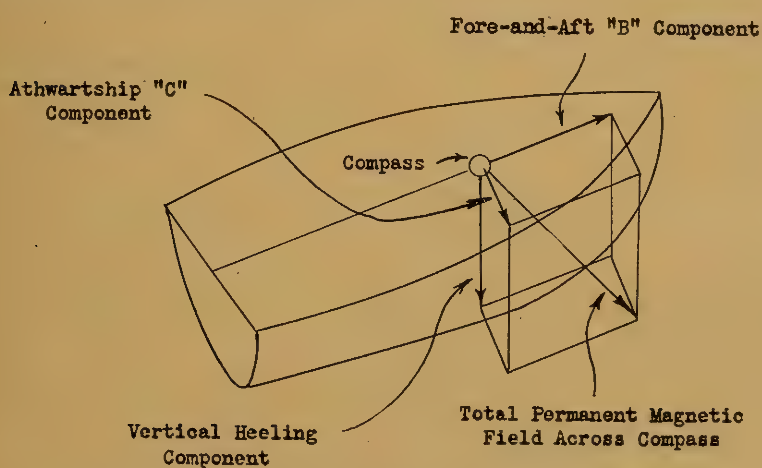


FIGURE 7.—Components of permanent magnetic field at the compass.

The effect of the *vertical permanent component* is the tendency to tilt the compass card and, in the event of rolling or pitching of the ship, to create *oscillating deflections* of the card. Oscillation effects accompanying roll are maximum on north and south compass headings, and those accompanying pitch are maximum on east and west compass headings.

The *horizontal B and C components of permanent magnetism* cause varying deviations of the compass as the ship swings in azimuth on an even keel. Plotting these deviations against *compass heading* will produce *sine and cosine curves*, as shown in figure 8. These *deviation curves* are called *semicircular curves* because they reverse direction in 180°.

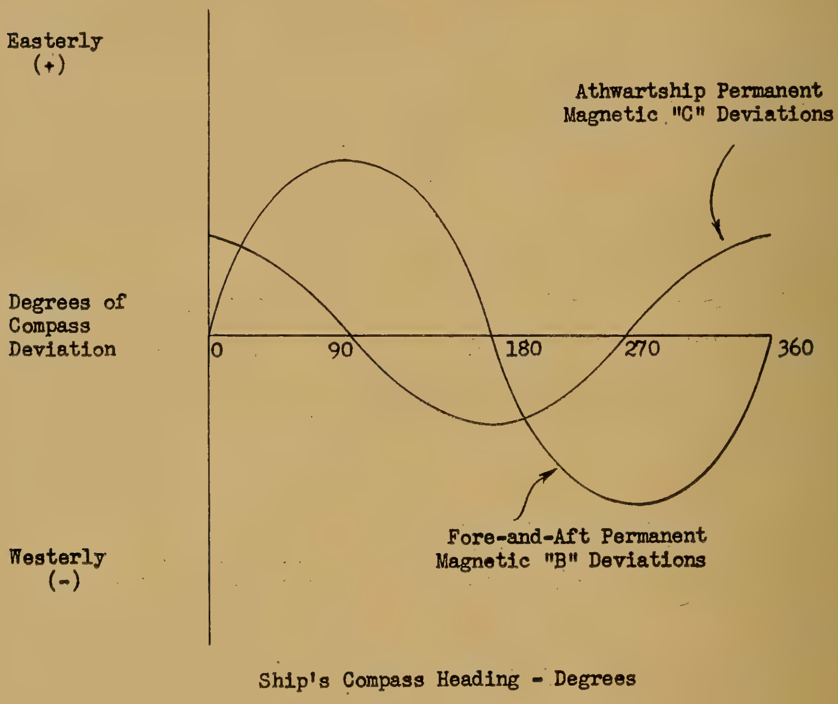


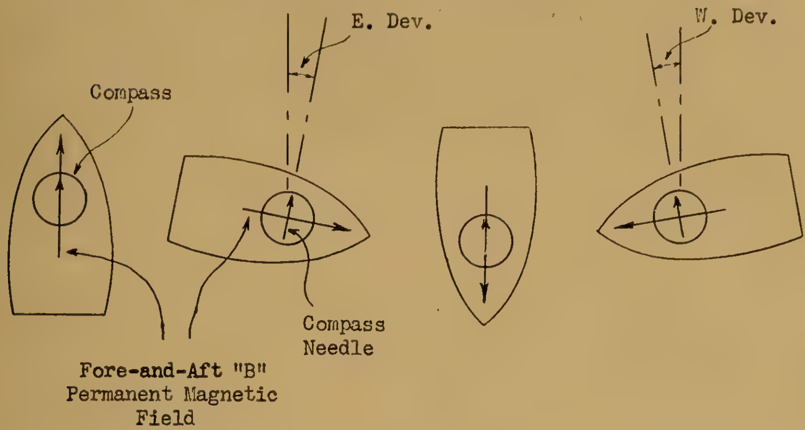
FIGURE 8.—Permanent magnetic deviation effects.

17. The permanent magnetic semicircular deviations can be illustrated by a series of simple sketches, representing a ship on successive compass headings, as in figures 9 and 10.

18. The ships illustrated in figures 9 and 10 above are pictured on *cardinal compass headings* rather than on *cardinal magnetic headings*, for two reasons:

(1) Deviations on compass headings are essential in order to represent sinusoidal curves which can be analyzed mathematically. This can be visualized by noting that the ship's component mag-

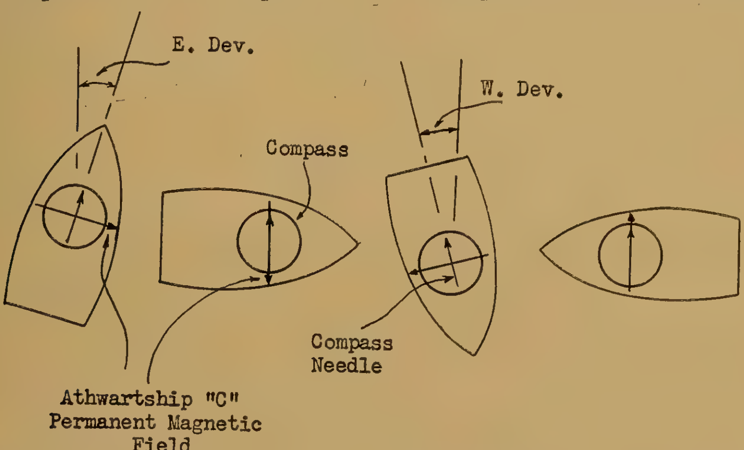
North heading by compass.	East heading by compass.	South heading by compass.	West heading by compass.



No deviation (change in directive force only).	Maximum deviation easterly.	No deviation (change in directive force only).	Maximum deviation westerly.

FIGURE 9.—Force diagrams for fore-and-aft permanent *B* magnetic field.

North heading by compass.	East heading by compass.	South heading by compass.	West heading by compass.



Maximum deviation easterly.	No deviation.	Maximum deviation westerly.	No deviation.

FIGURE 10.—Force diagrams for athwartship permanent *C* magnetic field.

netic fields are either in line with or perpendicular to the compass needles only on cardinal compass headings.

(2) Such a presentation illustrates the fact that the compass card tends to float in a fixed position, in line with the magnetic meridian. Deviations of the card to right or left (east or west) of the magnetic meridian result from the movement of the ship and its magnetic fields about the compass card.

19. Inasmuch as a compass deviation is caused by the existence of a force at the compass which is superimposed upon the normal *earths' directive force*, *H*, a *vector analysis* is helpful in determining deviations or the strength of deviating fields. For example, a ship as shown in figure 11 on an east magnetic heading will subject its compass to a combination of magnetic effects; namely, the earth's horizontal field *H*, and the deviating field *B*, at right angles to the field *H*. The compass needle will align itself in the *resultant field* which is represented by the *vector sum* of *H* and *B*, as shown. A similar analysis on the ship in figure 11 will reveal that the *resulting directive force* at the compass would be maximum on a north heading and minimum on a south heading, the deviations being zero for both conditions.

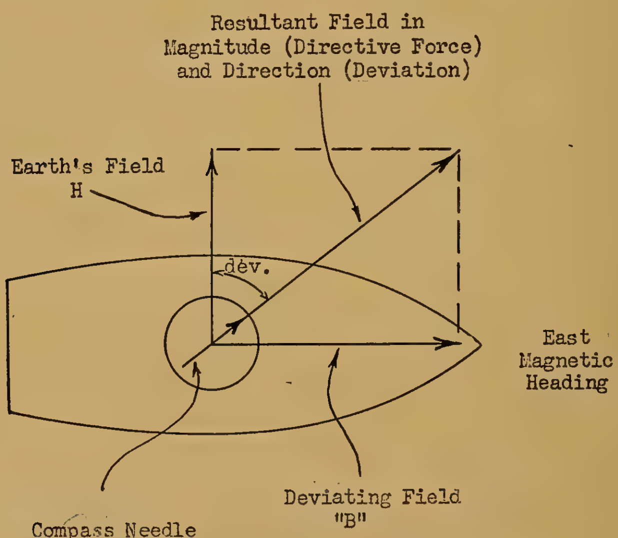


FIGURE 11.—General force diagram.

The magnitude of the deviation caused by the permanent *B* magnetic field will vary with different values of *H;* hence, deviations resulting from permanent magnetic fields will vary with the magnetic latitude of the ship.

20. Induced magnetism and its effects on the compass.—*Induced magnestism* varies with the strength of the surrounding field, the mass of metal, and the alignment of the metal in the field. Since the intensity of the earth's magnetic fields varies over the earth's surface, the induced magnetism in a ship will vary with latitude, heading, and heel of the ship.

21. With the ship on an even keel, the *resultant vertical induced magnetism*, if not directed through the compass itself, will create deviations which plot as a *semicircular deviation curve.* This is true because the vertical induction changes magnitude and polarity only with magnetic latitude and heel and not with heading of the ship. Therefore, as long as the ship is in the same magnetic latitude, its vertical induced pole swinging about the compass will produce the same effect on the compass as a permanent pole swinging about the compass. Figure 12 illustrates the vertical induced poles in the structures of a ship. Generally, this semicircular deviation will be a *B sine curve*, as shown in figure 13, since most ships are *symmetrical about the centerline* and have their *compasses mounted on the centerline.* The magnitude of these deviations will change with magnetic latitude changes because the directive force and the ship's vertical induction both change with magnetic latitude.

22. The masses of *horizontal soft iron* which are subject to *induced magnetization* create characteristic deviations, as indicated in figure 13. The *D* and *E* deviation curves are called *quadrantal curves* because they reverse polarity in each of the four quadrants.

23. *Symmetrical arrangements* of horizontal soft iron may exist about the compass in any of the patterns illustrated in figure 14.

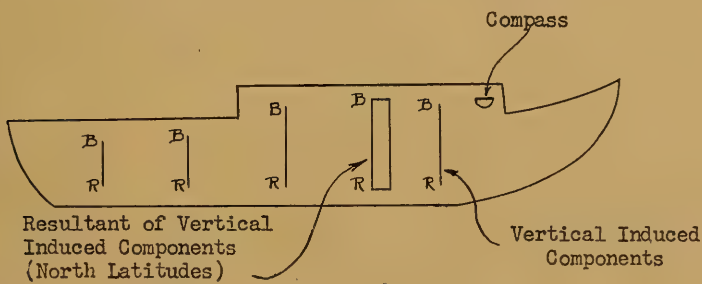


FIGURE 12.—Ship's vertical induced magnetism.

24. The deviations resulting from the earth's field induction of these symmetrical arrangements of horizontal soft iron are illustrated by the sketches in figure 15, showing the ship on a few different compass headings. The other heading effects may be similarly studied.

Such a *D* deviation curve is one of the several curves indicated in figure 13. It will be noted that these *D* deviations are *maximum on the intercardinal headings* and *zero on the cardinal headings.*

25. *Unsymmetrical arrangements* of horizontal soft iron may exist about the compass in a pattern similar to one of those in figure 16.

26. The deviations resulting from the earth's field induction of these unsymmetrical arrangements of horizontal soft iron are illustrated by the sketches in figure 17, showing the ship on a few different compass headings. The other heading effects may be similarly studied.

Such an E deviation curve is one of the several curves indicated in figure 13. It will be observed that these E deviations are *maximum on cardinal headings* and *zero on the intercardinal headings.*

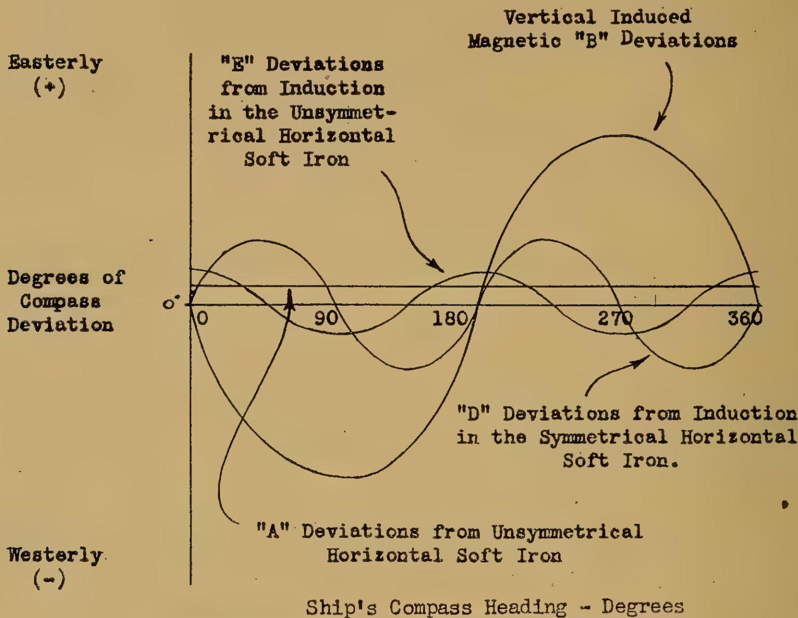


FIGURE 13.—Induced magnetic deviation effects.

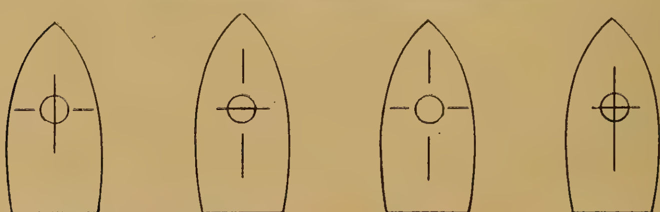


FIGURE 14.—Symmetrical arrangements of horizontal soft iron.

27. It is pointed out that these quadrantal deviations will not vary with latitude changes, because the horizontal induction varies proportionally with the directive force, H.

28. The earth's field induction in certain other unsymmetrical arrangements of horizontal soft iron create a constant A deviation curve. The magnetic A and E errors are of smaller magnitude than the other errors, but, when encountered, are generally found together, since they both result from unsymmetrical arrangements of

horizontal soft iron. In addition to this magnetic *A* error, there are constant *A* deviations resulting from (1) physical misalignments

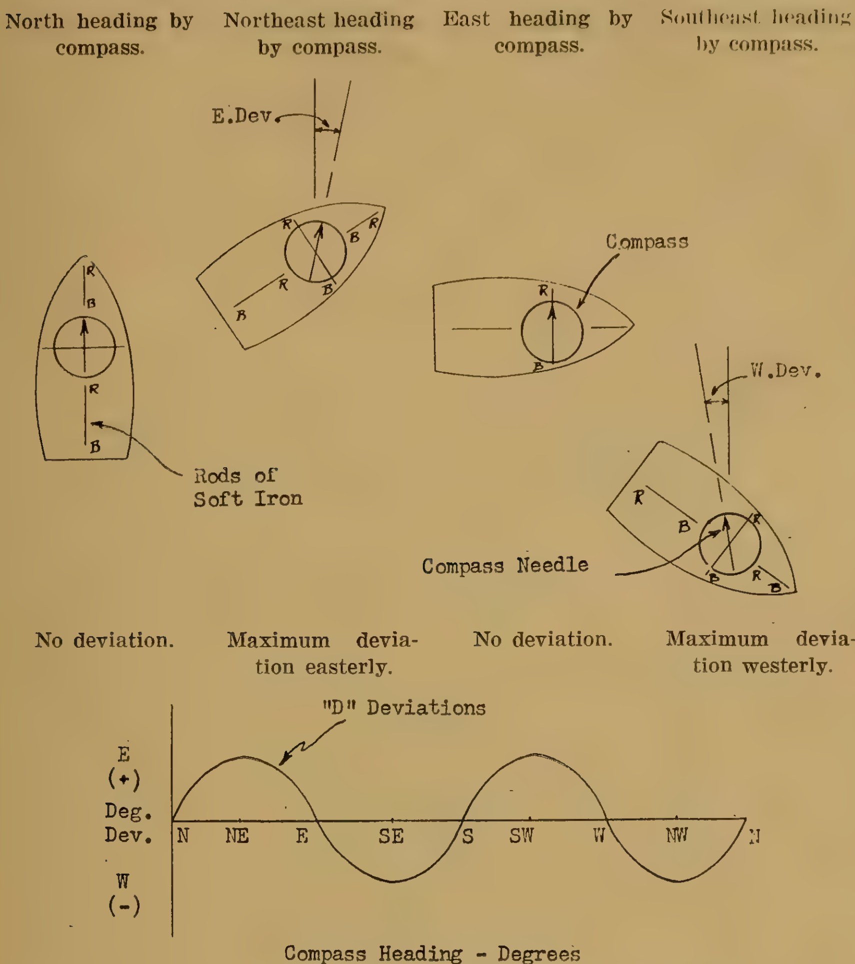


FIGURE 15.—Effects of symmetrical horizontal *D* induced magnetism.

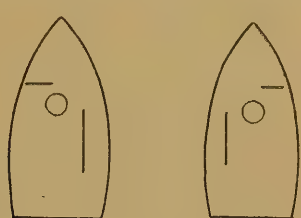


FIGURE 16.—Unsymmetrical arrangements of horizontal soft iron.

of the compass, pelorus, or gyro, or (2) errors in calculating the sun's azimuth, observing time, or taking bearings.

29. The nature, magnitude, and polarity of all these induced effects are dependent upon the disposition of metal, the symmetry or assymmetry of the ship, the location of the binnacle, the strength of the earth's magnetic field, and the angle of dip.

30. Certain *heeling errors*, in addition to those resulting from permanent magnetism, are created by the presence of both *horizontal* and *vertical soft iron* which experience changing induction as the

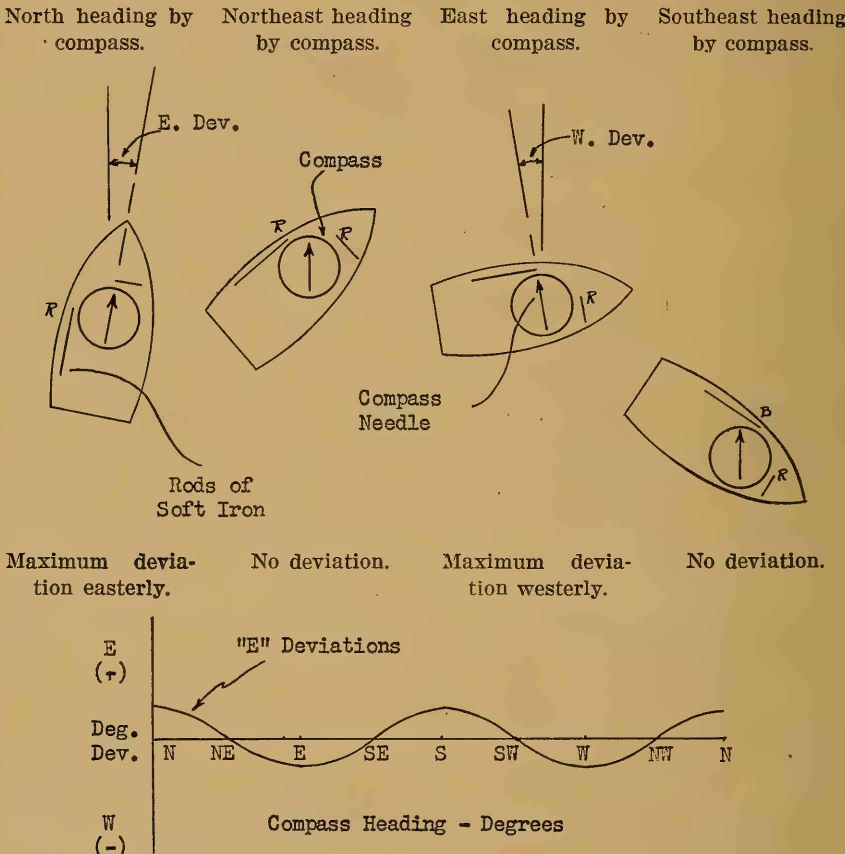


FIGURE 17.—Effects of unsymmetrical horizontal *E* induced magnetism.

ship rolls in the earth's magnetic field. This part of the heeling error will naturally change in magnitude with changes of magnetic latitude of the ship. *Oscillation effects* accompanying roll are maximum on north and south headings, just as with the permanent magnetic heeling errors.

31. **Adjustments and correctors.**—Since some magnetic effects remain *constant* for all magnetic latitudes and others *vary* with changes of magnetic latitude, each individual effect should be cor-

rected independently. Further, it is apparent that the best method of adjustment is to use (1) permanent magnet correctors to create equal and opposite vectors of permanent magnetic fields at the compass, and (2) soft iron correctors to assume induced magnetism, the effect of which will be equal and opposite to the induced effects of the ship for all magnetic latitude and heading conditions. The *compass binnacle* provides for the support of the compass and such correctors. Study of the binnacle in figure 18 will reveal that such correctors are present in the form of:

(1) Vertical permanent heeling magnet in the central vertical tube,

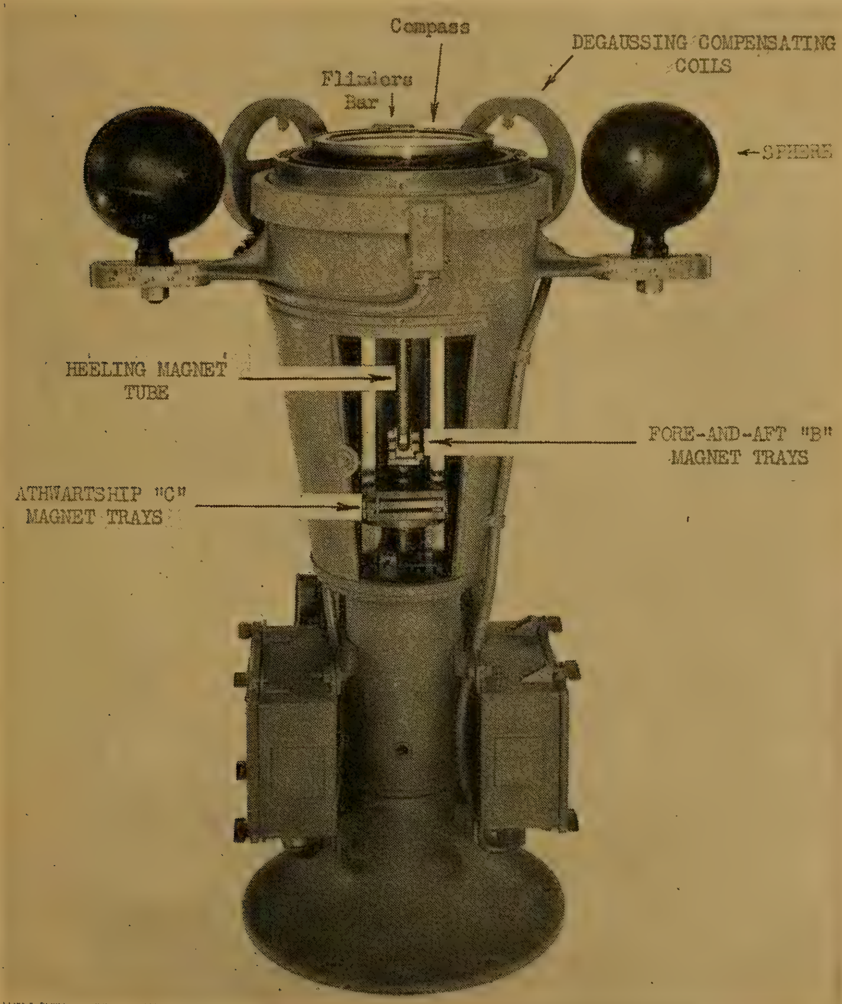


FIGURE 18.—Binnacle with compass and correctors.

(2) Fore-and-aft *B* permanent magnets in their trays,
(3) Athwartship *C* permanent magnets in their trays,
(4) Vertical soft iron Flinders bar in its external tube,
(5) Soft iron spheres.

Other type binnacles are shown in figures 39 to 43 inclusive.

The heeling magnet is the only corrector which corrects for *both* permanent and induced effects, and consequently must be *readjusted occasionally with latitude changes of the ship.*

32. The tabular summary of "Compass Errors and Adjustments," figure 19, summarizes all the various magnetic conditions in a ship, the types of deviation curves they create, the correctors for each effect, and headings on which each corrector is adjusted. Correctors should be applied *symmetrically* under all but exceptional conditions (discussed in detail later) and *as far away from the compass as possible* to preserve uniformity of magnetic fields about the compass needle array. Other details of corrector procedure are emphasized in chapter VIII.

Fortunately, each magnetic effect has a slightly different characteristic curve which makes identification and correction convenient. A complete deviation curve can be *analyzed* for its different components and thus the necessary corrections anticipated. A method for analyzing such curves is described in chapter IV.

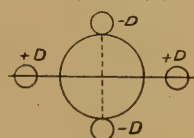
33. Compass operation.—Figure 20 illustrates a point about compass operation. Not only is an uncorrected compass subject to large deviations, but there will be sectors in which the compass may sluggishly turn with the ship and other sectors in which the compass is too unsteady to be used. These performances may be appreciated by visualizing a ship with deviations as shown in figure 20, as it swings from west through north toward east. Throughout this easterly swing the compass deviation is growing more easterly; and, whenever steering in this sector, the compass card sluggishly tries to follow the ship. Similarly, there is an unsteady sector from east through south to west. These sluggish and unsteady conditions are always characterized by the positive and negative slopes in a deviation curve. These conditions may also be associated with the maximum and minimum directive force acting on the compass. (See art. 19.) It will be observed that the maximum deviation occurs at the point of average directive force and that the zero deviations occur at the points of maximum and minimum directive force.

34. Correction of compass errors is generally achieved by applying correctors so as to *reduce the deviations* of the compass for all headings of the ship. Correction could be achieved, however, by applying correctors so as to *equalize the directive forces* across the compass posi-

Summary of Compass Errors and Adjustment

Coefficient	Type deviation curve	Compass headings of maximum deviation	Causes of such errors	Correctors for such errors	Magnetic or compass headings on which to apply correctors
A	Constant.	Same on all.	Human—error in calculations Physical-compass, gyro, pelorus alignment Magnetic-unsymmetrical arrangements of horiz. soft iron.	Check methods and calculations Check alignments Rare arrangement of soft iron rods.	Any.
B	Semicircular sin ϕ.	090° 270°	Fore-and-aft component of permanent magnetic field Induced magnetism in unsymmetrical vertical iron forward or aft of compass.	Fore-and-aft *B* magnets Flinders bar (forward or aft)	090° or 270°.
C	Semicircular cos ϕ.	000° 180°	Athwartship component of permanent magnetic field Induced magnetism in unsymmetrical vertical iron port or starboard of compass.	Athwartship *C* magnets Flinders bar (port or starboard)	000° or 180°.
D	Quadrantal sin 2ϕ.	045° 135° 225° 315°	Induced magnetism in all symmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (athwartship for $+D$) (fore and aft for $-D$) *See sketch a*	045°, 135°, 225°, or 315°.
E	Quadrantal cos 2ϕ.	000° 090° 180° 270°	Induced magnetism in all unsymmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (port fwd.—stb'd aft for $+E$) (stb'd fwd.—port aft for $-E$) *See sketch b*	000°, 090°, 180°, or 270°.
Heeling	Oscillations with roll or pitch. Deviations with constant list.	000° } roll 180° } 090° } pitch 270° }	Change in the horizontal component of the induced or permanent magnetic fields at the compass due to rolling or pitching of the ship.	Heeling magnet (must be readjusted for latitude changes).	090° or 270° with dip needle. 000° or 180° while rolling.

Deviation $= A + B \sin\phi + C \cos\phi + D \sin 2\phi + E \cos 2\phi$ (ϕ = compass heading).



(*Sketch a*)

(*Sketch b*)

FIGURE 19.

639720—45——3

tion for all headings of the ship. The deviation method is more generally used because it utilizes the compass itself to indicate results, rather than some additional instrument for measuring the intensity of magnetic fields.

35. Occasionally, the permanent magnetic effects at the location of the compass are so large that they overcome the earth's directive force, *H*. This condition will not only create sluggish and unsteady sectors, but may even *freeze* the compass to one reading or to one quadrant, regardless of the heading of the ship. Should the compass be so frozen, the polarity of the magnetism which must be attracting the compass needles is indicated; hence, correction may be effected simply by the application of permanent magnet correctors in suitable quantity to neutralize this magnetism. Whenever such adjustments are made, it would be well to have the ship placed on a heading such that the unfreezing of the compass needles will be immediately evi-

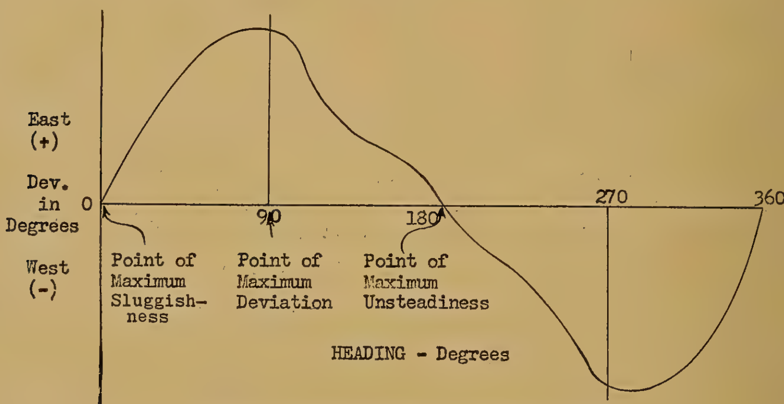


FIGURE 20.—Uncompensated deviation curve.

dent. For example, a ship whose compass is frozen to a north reading would require fore-and-aft *B* corrector magnets with the red ends forward in order to neutralize the existing blue pole which attracted the compass. If made on an east heading, such an adjustment would be practically complete when the compass card was freed so as to indicate an east heading.

36. Listed below are several reasons for correcting the errors of the magnetic compass.

(1) It is easier to use the magnetic compass if the deviations are small.

(2) Although the belief persists that it does not matter what the deviations are, as long as they are known, this belief is in

error inasmuch as conditions of sluggishness and unsteadiness accompany large deviations and consequently make the compass operationally unsatisfactory. This is the result of unequal directive forces on the compass as the ship swings in azimuth.

(3) Furthermore, even though the deviations are known, if they are large they will be subject to appreciable change with heel and latitude changes of the ship.

37. Subsequent chapters will deal with the methods of bringing a ship to the desired heading, the practical procedures of adjustment, and the methods of isolating deviation effects and of minimizing interaction effects between correctors.

Once properly adjusted, the magnetic compass deviations should remain constant until there is some change in the magnetic condition of the vessel resulting from magnetic treatment, shock from gunfire, vibration, repair, or structural changes. Frequently, the movement of nearby guns, doors, gyro repeaters, or cargo affects the compass greatly.

CHAPTER IV. TYPICAL DEVIATION CURVE AND THE ESTIMATION OF APPROXIMATE COEFFICIENTS

38. Simple analysis.—The data for the deviation curve illustrated in figure 21 is as follows:

Ship's compass heading:

		Deviation
N.	(000°)	10.5° E.
NE.	(045°)	20.0° E.
E.	(090°)	11.5° E.
SE.	(135°)	1.2° W.
S.	(180°)	5.5° W.
SW.	(225°)	8.0° W.
W.	(270°)	12.5° W.
NW.	(315°)	6.8° W.

Since A is the coefficient of *constant deviation*, its approximate value is obtained from the above data by estimating the mean of the algebraic sum of all the deviations. Throughout these computations the sign of *east deviation* is considered *plus*, and *west deviation* is considered *minus*.

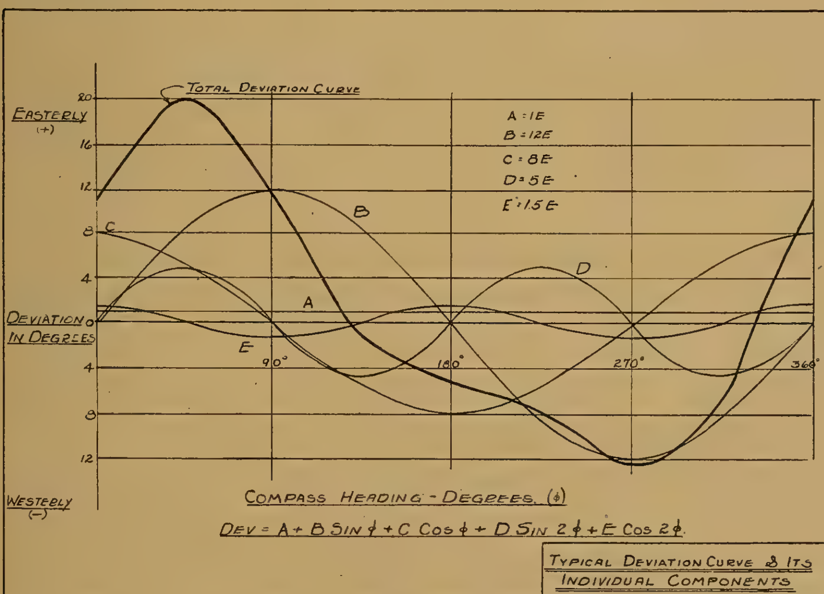


FIGURE 21.

$$8\ A = +10.5° + 20.0° + 11.5° - 1.2° - 5.5° - 8.0° - 12.5° - 6.8°$$

$$8\ A = +42.0° - 34.0° = +8.0°$$

$$A = +8.0°/8 = +1.0° = 1.0°\ \text{E.}$$

Since B is the coefficient of *semicircular sine deviation*, its value is maximum, but of opposite polarity, on 090° and 270° headings. The approximate B coefficient is estimated by taking the mean of the deviations at 090° and 270° with the sign at 270° reversed.

$$2\,B = +11.5° + (+12.5°) = +24.0°$$
$$B = +24.0°/2 = +12.0° = 12.0° \text{ E.}$$

Similarly since C is the coefficient of *semicircular cosine deviation*, its value is maximum, but of opposite polarity, on 000° and 180° headings; and the approximate C coefficient is estimated by taking the mean of the deviations at 000° and 180° with the sign at 180° reversed.

$$2\,C = +10.5° + (+5.5°) = +16°.0$$
$$C = +16.0°/2 = 8.0° \text{ E.}$$

D is the coefficient of *quadrantal sine deviation* having maximum, but alternately opposite, polarity on the intercardinal headings. Hence, the approximate D coefficient is estimated by taking the mean of the four intercardinal deviations with the signs at 135° and 315° reversed.

$$4\,D = (+20.0°) + (+1.2°) + (-8.0°) + (+6.8°) = +20.0°$$
$$D = 20.0°/4 = +5.0° = 5.0° \text{ E.}$$

E is the coefficient of *quadrantal cosine deviation* having maximum, but alternately opposite, polarity on the cardinal headings. Therefore, the approximate E coefficient is estimated by taking the mean of the four cardinal deviations with the signs at 090° and 270° reversed.

$$4\,E = (+10.5°) + (-11.5°) + (-5.5°) + (+12.5°) = +6.0°$$
$$E = +6.0°/4 = +1.5° = 1.5° \text{ E.}$$

These approximate coefficients are estimated from deviations on *compass headings* rather than on *magnetic headings*. The arithmetic solution of such coefficients will automatically assign the proper polarity to each coefficient.

Summarizing the above we find the approximate coefficients of the given deviation curve to be:

$$A = 1.0° \text{ E.}$$
$$B = 12.0° \text{ E.}$$
$$C = 8.0° \text{ E.}$$
$$D = 5.0° \text{ E.}$$
$$E = 1.5° \text{ E.}$$

Each of these coefficients represents a component of deviation which can be plotted as shown in figure 21. The polarity of each component in the first quadrant must agree with the polarity of the coefficient.

A check on the components in figure 21 will reveal that their summation equals the original curve.

This method of analysis is accurate only when the deviations are less than 20°. The mathematical expression for the deviation on any heading, using the approximate coefficients, is:

$$\text{Deviation} = A + B \sin \phi + C \cos \phi + D \sin 2\phi + E \cos 2\phi$$ (where ϕ represents compass heading)

39. Reasons for analysis.—This method of estimating approximate coefficients is convenient for:

(1) Analyzing an original deviation curve in order to anticipate necessary corrections.

(2) Analyzing a final deviation curve for the determination of additional refinements.

(3) Simplifying the actual adjustment procedure by anticipating effects of certain corrector changes on the deviations at all other headings.

40. Approximate and exact coefficients.—It is emphasized that the above estimations are for the so-called *approximate coefficients* and not for the *exact coefficients*. Approximate coefficients are in terms of angular deviations which are caused by certain magnetic forces; and as stated before, some of these deviations are subject to change with changes in the directive force, H. The exact coefficients are expressions of magnetic forces, dealing with; (*a*) arrangements of soft iron, (*b*) components of permanent magnetic fields, (*c*) components of the earth's magnetic field, and (*d*) the shielding factor λ. Thus, the exact coefficients are expressions of magnetic force which produce the deviations expressed by the approximate coefficients. The exact coefficients are for mathematical considerations, while the approximate coefficients are more practical for adjustment purposes. For this reason, the exact coefficients and the associated mathematics are not expanded further in this text. The German capital letters are used to designate the exact coefficients, whereas the English capital letters are used to designate the approximate coefficients.

41. Compass heading and magnetic heading.—When deviations are large, there is an applicable difference in the deviation curve if it is plotted on cross-section paper against compass headings or against magnetic headings of the ship. Not only is there a difference in the shape of the curves, but if only one curve is available navigators will find it difficult in applying deviations when converting from magnetic heading to compass heading, and vice versa. When deviations are small no conversion is necessary. Figure 22 illustrates the differences mentioned above by presenting the deviation values used in figure 21, as plotted against magnetic headings as well as against compass headings.

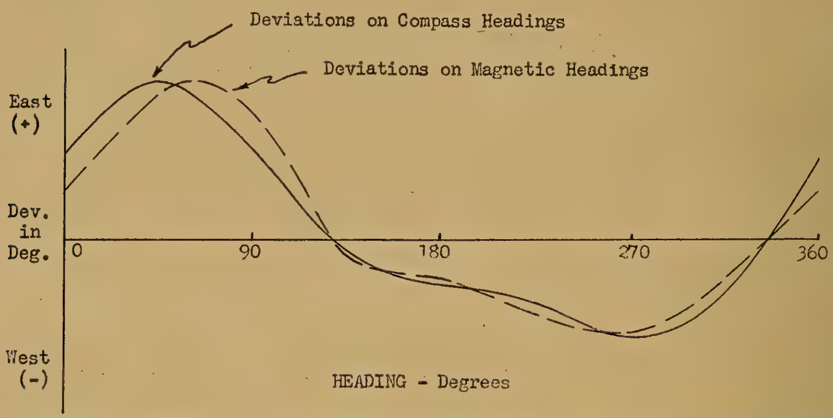


FIGURE 22.—Comparison of deviation curves. (Magnetic heading versus compass heading.)

42. Napier's diagram, NBS 1103.—The *Napier's diagram*, figure 23, is a convenient scheme which permits a ready conversion of deviations from compass to magnetic heading, or vice versa, with only one plot of the deviation curve. Deviations are plotted on the diagonal lines as instructed on the diagram. The curve in figure 23 represents the same deviation values as in figure 21. Such a plot on the Napier's form further reduces the calculations necessary for navigation by graphically adding or subtracting the appropriate deviation. *However, if the deviations are small, a Napier's plot is of little value.*

NAVSHIPS (250) NBS 1103 (Rev. 10-43) Degaussing {on / off} (NBS 1104 Dated July 4, 1943)

CURVE OF DEVIATIONS

(Constructed upon the Napier Diagram.)

Of the STANDARD *Compass No.* 100, *on board the*

U. S. S. WHIP

Lat. 37°00' N

Long. 76°15' W

Date of observations July 4, 1943

Compass courses on dotted lines. **Magnetic courses on solid lines.**

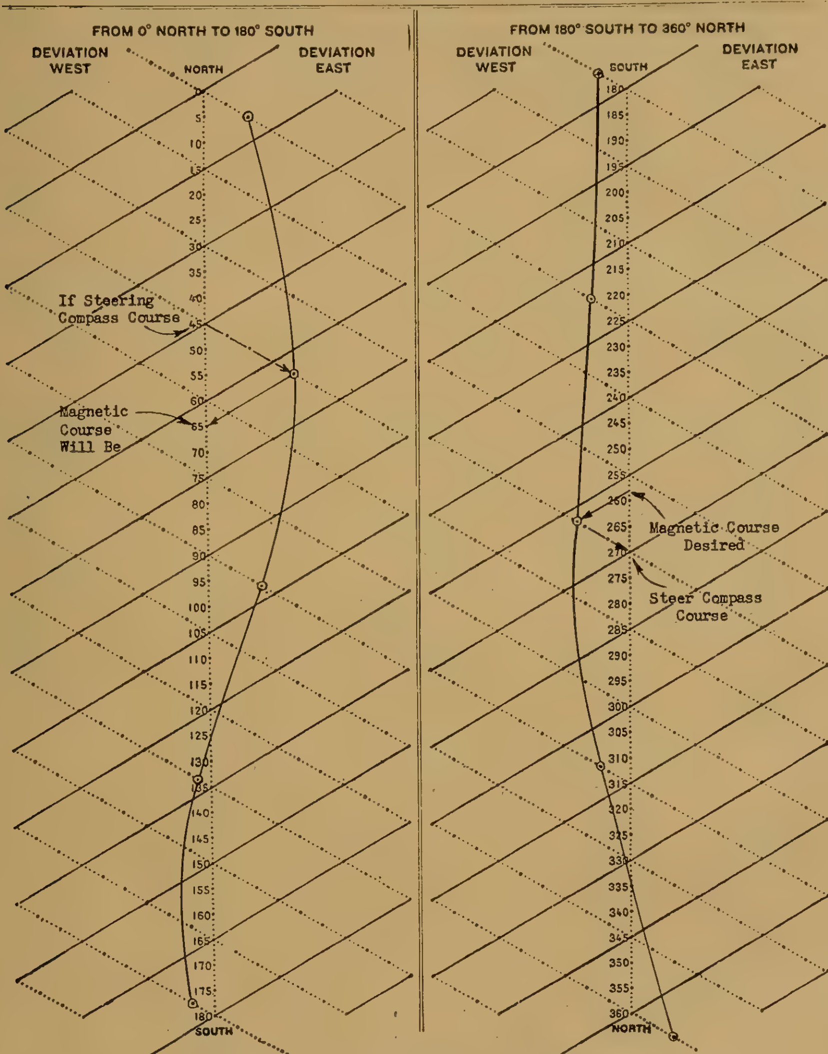


FIGURE 23.—Napier's diagram—Form NSB 1103.

CHAPTER V. SHIP'S HEADING

43. Ship's heading.—*Ship's heading* is the angle, expressed in degrees clockwise from north, of the ship's fore-and-aft line with respect to the true meridian or the magnetic meridian. When this angle is referred to the *true meridian*, it is called a *true heading*. When this angle is referred to the *magnetic meridian*, it is called a *magnetic heading*. Heading, as indicated on a particular compass, is termed the ship's *compass heading* by that compass. It is always essential to specify heading as true heading, magnetic heading, or compass heading. In order to obtain the heading of a ship, it is essential that the line through the pivot and the forward lubber's line of the compass be parallel to the fore-and-aft line of the ship. This applies also to the peloruses and gyro repeaters, which are used for observational purposes.

44. Variation.—*Variation* is the angle between the magnetic meridian and the true meridian, measured from true north. If this angle is to the *right of the true meridian*, the variation is *easterly*, and if the angle is to the *left of the true meridian*, the variation is *westerly*. The local variation and its small *annual change* are noted on the *compass rose* of all navigational charts. Thus the true and magnetic headings of a ship differ by the local variation. Figure 6 presents approximate variation values for the world, adapted from H. O. Chart 2406.

45. Deviation.—As previously explained, a ship's magnetic influence will generally cause the compass needle to deflect from the magnetic meridian. This angle of deflection is called *deviation*. If the north end of the needle points *east of the magnetic meridian*, the deviation is *easterly;* if it points *west of the magnetic meridian*, the deviation is *westerly*.

46. Heading relationships.—A summary of heading relationships follows:

(1) Deviation is the difference between the compass heading and the magnetic heading.

(2) Variation is the difference between the magnetic heading and the true heading.

(3) The algebraic sum of deviation and variation is the compass error.

Figure 24 illustrates such relationships. The following simple rules will assist in naming errors and in converting from one heading expression to another:

FIGURE 24.—Heading relationships (variation, deviation, and headings).

(1) Compass least (less than magnetic heading), deviation east.

Compass best (greater than magnetic heading), deviation west.

(2) In correcting (going from compass to magnetic to true), apply the sign algebraically (+East,−West).

In uncorrecting (going from true to magnetic to compass), reverse the sign (−East,+West).

Complete facility with such conversion of heading data is essential for expeditious compass adjustment procedure.

Typical heading relationships are tabulated below:

Compass heading 358°, magnetic heading 003°, deviation 5° E.
Compass heading 181°, magnetic heading 179°, deviation 2° W.
Compass heading 040°, deviation 3° E., magnetic heading 043°.
Compass heading 273°, deviation 2° W., magnetic heading 271°.
Magnetic heading 010°, deviation 2° E., compass course 008°.
Magnetic heading 270°, deviation 4° W., compass course 274°.
Magnetic heading 358°, variation 6° E., true heading 004°.
Magnetic heading 270°, variation 6° W., true heading 264°.
True heading 000°, variation 5° E., magnetic heading 355°.
True heading 083°, variation 7° W., magnetic heading 090°.

47. Use of compass heading and magnetic heading for adjustment.—The primary object of adjusting compasses is to reduce deviations (to make the magnetic heading and the compass heading identical, or as nearly so as possible). The two methods of accomplishing this are as follows:

(1) Place the ship on the desired *magnetic heading* and correct the compass so that it reads the same as this magnetic heading. This is the preferred method.

(2) Place the ship on the desired *compass heading* and determine the corresponding magnetic heading of the ship, and correct the compass so that it reads the same as this known magnetic heading. This method is used whenever it is impractical to place the ship on a steady magnetic heading for direct correction.

In using the *magnetic heading method*, the deviations of the compass are easily observed as the difference between the compass reading and the known magnetic heading of the ship. The difficulty in using this method lies in placing the ship on the desired magnetic heading and holding the ship steady on that heading while adjustments are being made.

When using the *compass heading method*, the ship can easily be brought to any desired compass heading, but the difficulty is in the determination of deviations. Further difficulty arises from the fact that the steersman is steering by an uncorrected compass whose deviations are changing as the necessary adjustments are being made.

Therefore, as each adjustment is being made, the steersman should attempt to hold the ship steady on that heading by some means other than the compass being corrected. Adjustments by this method are made as a series of approximations, for example:

Place the ship on any desired compass course, and correct the compass to read the corresponding magnetic heading. This will probably leave the ship on a course other than the desirable cardinal and intercardinal headings for compass adjustment. For accurate results, the above procedure should be repeated.

If the compass has no appreciable deviations, the deviations taken on compass headings will closely approximate those taken on magnetic headings. However, as the magnitude of errors increases, there will be a marked difference between the deviations taken on compass headings and those taken on magnetic headings. The Napier's Diagram affords a method of converting compass course to magnetic course, or vice versa, regardless of whether the deviations were taken on magnetic headings or compass headings. See article 42 for more details concerning its use.

48. Methods of placing ship on magnetic headings.—A ship may be brought on a magnetic heading by reference to a *gyrocompass*. The magnetic variation is applied to true heading to determine the gyro course which must be steered in order to place the ship on the desired magnetic heading. If the gyrocompass has any *error*, it must be taken into consideration. It is well to calculate all such problems through *true headings*, since short cuts on this procedure frequently lead to errors. Examples of such relationships are tabulated below:

To steer magnetic course	With variation	True course	With gyro error	Heading p. g. c. (per gyro compass)
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	6 W.	354	0	354
180	10 E.	190	0	190
270	4 W.	266	1 E.	265
315	6 E.	321	2 E	319
225	17 W.	208	2 W.	210
358	0	358	3 W.	001

The difference between gyro heading and magnetic heading will be constant on all headings as long as the gyrocompass error is constant and the variation does not change. This gyrocompass error may be determined by a comparison of the calculated true azimuth of the sun and the azimuth as observed on a synchronized repeater.

It is to be remembered that gyrocompasses have certain errors resulting from latitude and speed changes as well as turning errors, and that these errors are not always constant on all headings. For these reasons, the gyro error must be checked constantly, especially if the gyro is being used to obtain data for determining residual deviation curves of the magnetic compass.

49. A ship may be placed on a magnetic heading by aligning the vanes of an *azimuth circle* with the *sun* over the topside compass. The sun is a distant object whose *azimuth* (angle from the north) may be computed for any given time. Methods of calculating sun's azimuths are discussed in chapter VI. By setting the line of sight of the vanes at an angle to the right (or left) of the fore-and-aft line of the ship equal to the difference between the computed magnetic azimuth and the desired magnetic heading of the ship, and then swinging the ship until the sun is aligned with the vanes, the ship will be on the desired magnetic heading. Simple diagrams (as in fig. 25) with the ship and the sun drawn in their relative positions, will aid greatly in the visualization of each problem. The azimuth circle must always be kept *level* while making observations, particularly of celestial bodies.

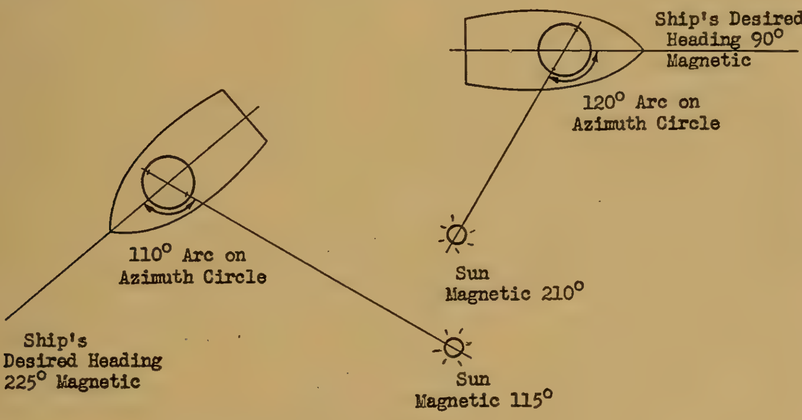


FIGURE 25.—Azimuth circle set-ups.

50. A *distant object* (ten or more miles away) may be used in conjunction with the *azimuth circle* for placing the ship on magnetic headings, provided the ship stays within a small area. This procedure is similar to that used with the sun except that the magnetic bearing of the object is constant. With an object 11.4 nautical miles distant, a change in position of 400 yards at right angles to the line of sight introduces an error of 1°.

51. A *pelorus* may be used to place a ship on a magnetic heading using the *sun's azimuth* in much the same manner as with the azimuth circle. Use of the pelorus has the further advantage in that the magnetic heading of the ship can be observed continuously as the ship swings. Such a procedure would be as follows:

> The forward sight vane is clamped to the dial at the value of the sun's magnetic azimuth, and the sight vanes are then trained so that the sun is reflected in the mirror. As the ship turns, the magnetic heading is always observed under the forward lubber's line if the vanes are kept on the sun, and this will serve as a guide for bringing the ship onto any desired magnetic heading. As the desired magnetic course is approached, the compass can be read and corrected, even before that magnetic course is actually obtained; and a final check can be made when the ship is on the exact course. The pelorus must always be kept in a *level* position while making observations, particularly of celestial bodies.

52. A *distant object* can be used in conjunction with the *pelorus*, as with the azimuth circle, in order to place the ship on magnetic headings, provided the ship stays within a small area. (See art. 50.)

53. **Methods of determining deviations on compass heading.**—The deviations on compass headings may be obtained by a comparison of the calculated magnetic *azimuth of the sun* and the azimuth as observed on the compass by use of an *azimuth circle*. Methods of calculating sun's azimuths are discussed in chapter VI. The ship is placed on the desired compass heading and an azimuth of the sun is taken on the face of the compass card. The difference in degrees between the observed azimuth and the calculated magnetic azimuth of the sun is the deviation on that compass course.

54. The *pelorus* may also be used in conjunction with the *sun's azimuth* to obtain deviations on compass headings. The ship is brought to the desired compass heading, and the forward sight vane is set on the calculated value of the sun's magnetic azimuth. The sight vanes are then trained on the sun, and the magnetic heading of the ship is indicated under the forward lubber's line of the pelorus. The difference in degrees between the compass heading and magnetic heading of the ship indicated by the pelorus, is the deviation on that compass course.

55. The *azimuth circle* or *pelorus* can be used in conjunction with *ranges* or a *distant object* to obtain deviations on compass courses. The procedure is similar to that used with the sun. A *range* consists of any two objects or markers, one in the foreground and the other in the background, which establishes a line of sight having a known magnetic bearing. The true bearing of such a range is determined from a local chart; this true bearing is converted to the magnetic bearing by applying the variation, corrected for annual change, as given on the nearest compass rose of the

chart. *Multiple ranges* consist of several markers in the background and a single marker in the foreground, or vice versa. The ship is brought to the desired compass course and, at the instant of crossing the line of sight of the range, a bearing is taken with the azimuth circle or pelorus. With the azimuth circle, the difference in degrees between the observed bearing of the range on the face of the compass and the known magnetic bearing of the range is the deviation on that compass course. If using a pelorus, the forward sight vanes are set to the magnetic bearing of the range and the magnetic heading of the ship is read under the forward lubber's line of the pelorus at the instant of taking a sight on the range. The deviation is the difference in degrees between the compass heading of the ship and the known magnetic heading of the ship as indicated by pelorus.

56. Deviations on compass courses may be obtained by the use of *reciprocal bearings.* A pelorus is set up on shore and the south end of the dial is aligned with magnetic north. A ship can then sight the pelorus on shore, using an azimuth circle or pelorus, at the same instant the observer on shore sights the ship. The ship's bearing from shore on the reversed pelorus is the magnetic bearing of the shore position from the ship. Continuous communication between ship and shore is necessary and must be so arranged as to provide *simultaneous observations.* Two methods of such communication are by flashing lights and, preferably, by short range two-way voice radio.

Additional methods of determining deviations are by the use of azimuths of the moon, stars, and planets. For detailed information as to the calculation of the azimuths of these celestial bodies, consult any standard work on celestial navigation.

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CHAPTER VI. AZIMUTHS

57. Azimuth Z_n.—The true *azimuth* of a body is the true bearing of that body relative to the north geographic pole, measured on the horizon clockwise from 0° to 360° Magnetic bearings or azimuths differ from true bearings or azimuths by the local variation.

58. Azimuths of the sun.—The azimuth of the sun at any instant can be determined by solving the astronomical triangle established by the observer's position, the sun, and the elevated pole. Since accurate compass bearings of the sun can readily be observed for comparison with the sun's azimuth to obtain the compass error, the sun is a valuable reference point for compass adjustment and compensation. The azimuths of other celestial bodies for any instant can similarly be determined, but are less practical for compass work because of the poor visibility of stars and the more variable time rates and declinations of the moon and planets. Hence, subsequent explanations concern themselves only with the sun and its azimuths.

59. Azimuth angle Z.—United States Navy Hydrographic Office publications H. O. 71 and H. O. 214 tabulate the solutions of the astronomical triangle discussed above. For convenience of tabulation, the *relative azimuths* given in these tables are measured either east or west from the elevated geographic pole. Hence, certain rules must be observed in obtaining a true azimuth, Z_n, from an azimuth angle, Z, in these tables. These rules are as follows:

1. For North latitudes:

   (*a*) $Z_n = Z$ if the sun is east of the meridian.
   (*b*) $Z_n = 360° - Z$ if the sun is west of the meridian.

2. For South latitudes:

   (*a*) $Z_n = 180° - Z$ if the sun is east of the meridian.
   (*b*) $Z_n = 180° + Z$ if the sun is west of the meridian.

It must be remembered that in order to obtain magnetic azimuths from true azimuths the appropriate variation must be applied to the true azimuths.

60. Equation of time (Eq. T.).—Apparent time is measured by the apparent motion of the true sun, and at any instant it differs from mean sun time by the *equation of time* (*Eq. T.*). The Eq. T. is tabulated in the *Nautical Almanac* for every even hour of *Greenwich civil time* (*G. C. T.*) throughout the year.

61. Meridian angle, t.—The *meridian angle*, *t*, of the sun is the angle at the pole measured from the meridian of the observer to the hour circle of the sun eastward or westward from 0^h to 12^h (or from 0° to 180°). Thus *t* is an expression in hours, minutes, and seconds (or in degrees, minutes, and seconds) denoting the apparent sun's position east or west of the local meridian.

62. Hour angle (H. A.).—The *hour angle* (*H. A.*) of the sun is the angle at the pole measured from a given meridian to the hour circle of the sun, positively westward from 0^h to 24^h (or from 0° to 360°). H. A., when referred to the local meridian, is called the *local hour angle* (*L. H. A.*) and is, therefore, another method for expressing meridian angle, *t*. Thus, *t* for the sun west of the observer's meridian is equal to the L. H. A. of the sun, while *t* for the sun east of the meridian is equal to 24^h minus L. H. A.

63. Local apparent time (L. A. T.).—*Local apparent time* (*L. A. T.*) is another method for expressing meridian angle, *t*, or hour angle, H. A. Since H. A. is measured from the upper branch of the meridian (noon), and L. A. T. commences when the sun crosses the lower branch of the meridian (midnight), L. A. T. and L. H. A. will differ by 12 hours. Thus 1200 L. A. T. is 0° of L. H. A.

To find L. A. T., first convert *zone time* to its equivalent *Greenwich civil time* (*G. C. T.*). Zone time is standard time in principle, but differs from standard time in that it is kept and expressed on the 0^h to 24^h basis, the suffixes a. m. and p. m. not being used. Thus 8:15 a. m. standard time is 0815 zone time, and 3:15 p. m. standard time is 1515 zone time. The earth is considered as divided into 24 time zones, each 15° of longitude in width, the middle meridians of the zones being 15° or 1 hour of time apart. The time kept throughout any zone is the civil time of its middle meridian. Thus, zone time differs from G. C. T. by 1 or more whole hours. (See exception in next paragraph.) When the zone is west of Greenwich the zone description, expressed in time, is added to the zone time to obtain G. C. T.; conversely, when the zone is east of Greenwich the zone description, expressed in time, is subtracted from zone time to obtain G. C. T. (See table in *Nautical Almanac* for conversion of arc to time.

There are certain excepted areas and countries where the legal time differs from the zone time. In such places the zone description is the exact amount in hours, minutes, and seconds that must be applied to the legal time to get G. C. T. (See U. S. Navy Hydrographic Office chart H. O. 5192.)

Having obained G. C. T., select from the *Nautical Almanac* the Eq. T. corresponding to this G. C. T. and date, and apply it to the G. C. T. in accordance with the sign given. The result will be *Green-*

wich apparent time (*G. A. T.*). To this G. A. T. apply the observer's longitude, converted to time (subtract if observer's longitude is west of Greenwich and add if observer's longitude is east of Greenwich), and the result will be L. A. T. If operating under *War Time* or *Daylight Saving Time*, conversion should first be made to zone time before any other conversions are made.

64. Sample time calculation.—Calculate the L. A. T. for 0900.0 zone time on September 29, 1944. Assumed position is Norfolk, Va., U. S. A., latitude 37°00′ N., longitude 76°15′ W. (+5 zone). Further assuming that the watch is correctly set on zone time at Norfolk, determine the error of the watch on L. A. T.

	h	m	s	
Zone time (watch time)	09	00	00	Sept. 29, 1944.
Zone description (+)	5	00	00	(+ 5 zone).
G. C. T	14	00	00	Sept. 29, 1944.
Eq. T (+)		9	42.4	(pp. 30, 1944 *Nautical Almanac*).
G. A. T	14	09	42.4	
Observer's longitude (−)	5	05	00	(Longitude 76°15′ W.).
L. A. T	09	04	42.4	
Watch time	09	00	00	
Error of watch on L. A. T (+)	00	04	42.4	

Thus on September 29, 1944, 0900.0 zone time corresponds to 0904.7 L. A. T.

65. When preparing and using a *table* or *curve of azimuths*, as discussed in article 70, it must be remembered that the difference between zone time and L. A. T. will differ slightly for each hour of the day in a given locality because the Eq. T. is constantly changing. However, a study of the *Nautical Almanac* will reveal that the hourly difference in the Eq. T. is so slight as to be negligible over a period of several hours. Thus, if it is desired to use azimuths of the sun from 0700 to 1100 zone time, the middle time of that period is selected and the error of the watch on L. A. T. is calculated. If at the beginning of the period, the equivalent L. A. T. is set on a well regulated watch, it may then be used to obtain L. A. T. for the entire period without appreciable error.

66. Use of azimuth tables.—The following arguments are available for solution of the astronomical triangle:

(1) Meridian angle, *t*.
(2) Declination, *d*.
(3) Latitude, *L*.

Inasmuch as the various azimuth tables tabulate the solution of the astronomical triangle, in terms of t, d, and L, these arguments are generally used to enter the tables. The meridian angle, t, is expressed either as L. A. T. or as L. H. A., as previously discussed. The declination d, of the sun, with its sign, is obtained from the *Nautical Almanac* for the appropriate G. C. T. and date. The latitude, L, may be obtained from a chart of the locality.

To obtain the sun's true azimuth, Z_n, from the azimuth tables the following basic procedure is presented:

(1) Compute the meridian angle, t.

(2) Enter the proper part of the table, according to whether the latitude and declination are of the same or different names, and select the page headed with the value of the latitude, L.

(3) Select the declination column headed with the value of declination, d. In this column select the value of Z tabulated against the desired value of meridian angle, t.

(4) Convert Z to Z_n according to rules previously given.

67. Use of United States Navy Hydrographic Office Publication H. O. 71.—In the H. O. 71 tables the meridian angle, t, is expressed as apparent time a. m. and p. m. for each 10 minutes, and the latitude and declination are given for each whole degree. Apparent time, as tabulated, can be converted to L. A. T., as defined, by using the a. m. values directly and by adding 12^h to the p. m. values. This table consists of a single volume covering declinations from 0° to 23° and is, therefore, convenient for use with the sun.

Interpolation in H. O. 71 is necessary when the values of L and d are not in whole degree and the L. A. T. is not an even ten-minute value. To interpolate, list the necessary arguments, t, d, and L; t to the nearest tenth of a minute, and d and L to the nearest tenth of a degree. Select the value of Z for the next lower degree of latitude and declination and the next lower 10 minutes of the tabulated value of t. This value of Z is the *base*.

Then keeping L and d, as before, select the value of Z for the next higher tabulated value of t. The difference between this Z and the base Z is caused by a ten minute change in L. A. T. Multiply this difference by the difference in the number of minutes, expressed to the nearest tenth of a minute, between the given value of L. A. T. and the L. A. T. used as a base, and divide by ten. This result is the *time correction*.

Next, using the values of t and L as used for the base, select the value of d which is 1° greater than d used for the base Z. The difference between this value of Z and the base Z is the difference for 1° change of declination. Multiply this difference by the difference in the value of *d* as given, and the value of *d* used as a base, expressed to the nearest tenth of a degree. This result is the *declination correction.*

Repeat the above operations described for declination correction to obtain *latitude correction*, using an *L* difference of 1°.

Find the algebraic sum of all the corrections and apply algebraically to the base to obtain the *interpolated value* of *Z*. Convert this *Z* to Z_n according to rules previously given.

68. Sample azimuth calculation.—Given the data below, find the deviation of the compass using H. O. 71.

L. A. T.	0842.3.
Declination, *d*	13°–23′.1 N.
Latitude, *L*	37°–16′.0 N.
Z (p. s. c.)	108°.5.
Variation from chart	6°.5 W.

		Diff. for	Corr. for +	−
t	$3^h-17.7^m$ E. (L. A. T. 0842.3)	$10^m=-118'$	$7.7^m=$	91′
d	13°.4 N.	1°= −63′	0.4°=	25′
L	37°.3 N.	1°= +51′	0.3°=15′	
			15′	116′
				15′
			Corr.(−)	101′
				or 1°—41′

Base	106°—46′	(From same name table— L. A. T.=0850.0 or $t=3^h-10^m.0$ E. d=13°.0 N. L=37°.0 N.)
Corr. (−)	1°—41′	
Z	105°—05′ or 105°.1	
Z_n	105°.1	(Since $Z_n=Z$ in this case)
Variation	6°.5 W.	
Z (magnetic)	111°.6	
Z (p. s. c.)	108°.5	
Deviation	3°.1 E.	(*Answer*)

69. Use of United States Navy Hydrographic Office Publication H. O. 214.—In the H. O. 214 tables the meridian angle, *t*, is tabulated under H. A. for every degree of arc (4 minutes of time), the latitude, L, is given for each whole degree, and the declination, *d*, is given for each one-half degree. These tables present altitudes (above 5°) and azimuths for declinations up to 75°, and are therefore applicable for use with the moon, planets, and navigational stars, as well as with the sun. H. O. 214 is divided into 9 volumes, each volume covering 10° of latitude.

Interpolation for azimuth angles in H. O. 214 may be made in a manner similar to that previously described for H. O. 71.

70. Curve of magnetic azimuths.—When swinging ship for purposes of compass correction it is necessary for the operator to be able to determine the sun's azimuth, either true or magnetic, at any moment without the delay which would result if each azimuth had to be obtained from the tables as required. Therefore, a prepared *table* or *curve of azimuths* for the required length of time, plotted against L. A. T. or watch time, is very useful and will facilitate the procedure. For such a table or curve, the Eq. T. and the sun's declination may be used as of the middle instant of the pre-selected period without appreciable error, as discussed previously under article 65. If interpolation is necessary the combined correction for t, d, and L, as determined for the middle instant, may be used on the base values of Z throughout the period provided the period does not border too close to noon L. A. T. It is simpler, of course, to make such a table or curve of azimuths for *even units* of L. A. T., thus eliminating the t correction.

Extreme care must be exercised when using the sun between 1100 and 1300 L. A. T., since the azimuth changes very rapidly at that time and the sun is generally at a high altitude.

CHAPTER VII. PRACTICAL PROCEDURES FOR MAGNETIC COMPASS ADJUSTMENT

With an understanding of the theory of magnetic effects and their corrections, the methods of analyzing deviation curves, and the methods of placing a ship on any desired heading, the operator is ready to begin adjustment.

71. Dockside tests and adjustments.—Chapter I, "Procedure for Magnetic Compass Adjustment," is in general self-explanatory, and brings to the attention of the operator many physical checks which are desirable before beginning an adjustment. The theoretical adjustment is based on the premise that all the physical arrangements are perfect, and much time and trouble will be saved while at sea if these checks are made before attempting the actual magnet and soft iron corrector adjustments. A few of these checks are amplified below.

72. Should the compass have a small bubble, compass fluid may be added by means of the filling plug on the side of the compass bowl. If an appreciable amount of compass liquid has leaked out, a careful check should be made on the condition of the sealing gasket and filling plug. United States Navy compass liquid may be a mixture of 45 percent grain alcohol and 55 percent distilled water, or a kerosene-type fluid (specification AN–C–116 or AN–W–C–551). These fluids are not interchangeable.

73. The compass should be removed from the ship and taken to some place free from all magnetic influences except the earth's magnetic field for tests of *moment* and *sensibility*. These tests involve measurements of the time of vibration and the ability of the compass card to return to a consistent reading after deflection. These tests will indicate the condition of the pivot, jewel, and magnetic strength of the compass needles. (See Dutton's *Navigation and Nautical Astronomy* or NBS. 1107 for such test data on standard Navy compass equipment.)

74. A careful check should be made on the spheres and Flinders bar for *residual magnetism*. Move the spheres as close to the compass as possible and slowly rotate each sphere separately. Any appreciable deflection (2° or more) of the compass needles resulting from this rotation indicates residual magnetism in the spheres. This test may be made with the ship on any steady heading. The Flinders bar magnetization check is preferably made with the ship on steady east or west compass headings. To make this check: (*a*) note the compass reading with the Flinders bar in the holder, (*b*) invert the

Flinders bar in the holder and again note the compass reading. Any appreciable difference (2° or more) between these observed readings indicates residual magnetism in the Flinders bar. Spheres or Flinders bars which show signs of such residual magnetism should be *annealed*, i. e., heated to a dull red and allowed to cool slowly.

75. Correct alignment of the lubber's line of the compass, gyro repeater, and pelorus with the fore-and-aft line of the ship is of major importance. Such a misalignment will produce a constant *A* error in the curve of deviations. Any of these instruments may be aligned correctly with the fore-and-aft line of the ship by using the azimuth circle and a metal tape measure. Should the instrument be located on the centerline of the ship, a sight is taken on a mast or other object on the centerline. In the case of an instrument off the centerline, a metal tape measure is used to measure the distance from the centerline of the ship to the center of the instrument. A similar measurement from the centerline is made forward or abaft the subject instrument and reference marks are placed on the deck. Sights are then taken on these marks.

Standard compasses should always be aligned so that the lubber's line of the compass is parallel to the fore-and-aft line of the ship. Steering compasses may occasionally be misaligned in this respect in order to correct for any magnetic *A* error present, as discussed in article 81.

76. In addition to the physical checks listed in chapter I, there are other precautions to be observed in order to assure continued satisfactory compass operation. These precautions are mentioned to bring to the attention of the adjuster certain conditions which might disturb compass operation. These precautions are listed in chapter I and are discussed further in chapter IX.

Expeditious compass adjustment is dependent upon the application of the various correctors in a *logical sequence* so as to achieve the final adjustment with a minimum number of steps. Certain adjustments may be made conveniently at dockside so as to simplify the adjustment procedures at sea.

77. Inasmuch as the Flinders bar is subject to induction from several of the other correctors and, since its adjustment is not dependent on any single observation, this adjustment is logically made first. This adjustment is made by one of the following methods.

(1) Deviation data obtained at two different magnetic latitudes may be utilized to *calculate* the proper length of Flinders bar for any particular compass location. Details of the acquisition of such data and the calculations involved are presented in arts. 95 to 99, inclusive. The utilization of vertical field "Z-loop" coils is being explored as a method for simulating this procedure.

(2) If the above method is impractical the Flinders bar length will have to be set approximately by:

(*a*) Using an *empirical amount* of Flinders bar which has been found correct for other ships of similar structure.

(*b*) Studying the arrangement of masts, stacks, and other vertical structures and *estimating* the Flinders-bar correction required.

If none of these methods is suitable, the Flinders bar would best be *omitted* until data are acquired.

The iron sections of Flinders bar should be continuous and at the top of the tube with the longest section at the top. Wooden spacers are used at the bottom of the tube to achieve such spacing.

78. Having adjusted the length of Flinders bar, place the spheres on the bracket arms at the best approximate position. If the compass has been adjusted previously, place the spheres at the best position as indicated by the last deviation table. In the event the compass has never been adjusted, place the spheres at midposition on the bracket arms.

79. The next adjustment is the positioning of the heeling magnet by means of a properly balanced dip needle, as discussed in chapter XV.

80. These three adjustments at dockside—Flinders bar, spheres, and heeling magnet—will properly establish the conditions of mutual induction and shielding on the compass, such that a minimum of procedures at sea will complete the adjustment.

Compass coil installations should be adjusted at dockside in order to save time at sea. Chapter X discusses this procedure.

81. Expected errors.—The "Summary of Compass Errors and Adjustment," figure 19, lists six different coefficients or types of deviation errors with their causes and corresponding correctors. A discussion of these coefficients follows:

The *A* error is more generally caused by the miscalculation of azimuths or by physical misalignments, rather than magnetic effects of unsymmetrical arrangements of horizontal soft iron. Thus if the physical alignments are checked at dockside, and if care is exercised in making all calculations, the *A* error will be rather insignificant. On a standard compass where an azimuth or bearing circle is used to determine deviations, any observed *A* error will be *solely* magnetic *A* error. This results from the fact that such readings are taken on the face of the compass card itself rather than at the lubber's line of the compass. On a steering compass where deviations are obtained by a comparison of the compass lubber's line reading with the ship's magnetic head as determined by pelorus or gyro, any observed *A* error may be a *combination* of magetnic *A* and mechanical *A* (misalignment). These facts explain the procedure wherein only mechanical

A is corrected on the standard compass by realignment of the binnacle, and both mechanical *A* and magnetic *A* errors are corrected on the steering compass by realignment of the binnacle (see art. 75). On the standard compass, the mechanical *A* error may be isolated from the magnetic *A* error by making the following observations simultaneously:

(1) Record a curve of deviations by using an azimuth (or bearing) circle. Any *A* error found will be solely magnetic *A*.

(2) Record a curve of deviations by comparison of the compass lubber's line reading with the ship's magnetic head as determined by pelorus or by gyro. Any *A* error found will be a combination of mechanical *A* and magnetic *A*.

The mechanical *A* on the standard compass is then found by subtracting the *A* found in the first instance from the total *A* found in the second instance; and is corrected by rotating the binnacle in the proper direction by that amount. It is neither convenient nor necessary to isolate the two types of *A* on the steering compass and all *A* found by using the pelorus or gyro may be removed by rotating the binnacle in the proper direction by that amount.

The *B* error results from two different causes, namely: the fore-and-aft permanent magnetic field across the compass, and a resultant unsymmetrical vertical induced effect forward or aft of the compass. The former is corrected by the use of fore-and-aft *B* magnets, and the latter is corrected by the use of the Flinders bar forward or aft of compass. Inasmuch as the Flinders bar setting has been made at dockside, any *B* error remaining is corrected by the use of fore-and-aft *B* magnets.

The *C* error has two causes, namely: the athwartship permanent magnetic field across the compass, and a resultant unsymmetrical vertical induced effect athwartship of the compass. The former is corrected by the use of athwartship *C* magnets, and the latter would be corrected by the use of Flinders bar to port or starboard of the compass; but, inasmuch as this vertical induced effect is very rare, the *C* error is corrected by athwartship *C* magnets only.

The *D* error is due only to induction in the symmetrical arrangements of horizontal soft iron, and requires correction by spheres, generally athwartship of the compass.

The existence of *E* error of appreciable magnitude is rare, since it is caused by induction in the unsymmetrical arrangements of horizontal soft iron. When this error is appreciable it may be corrected by slewing the spheres, as described in chapter XVII.

As has been stated previously, the heeling error is most practically adjusted at dockside with a balanced dip needle. (See chapter XV).

82. A summary of the above discussion reveals that certain errors

are rare, and others have been corrected by adjustments at dockside. Therefore, for most ships, there remain only three errors to be corrected at sea, namely, the *B*, *C*, and *D* errors. These are corrected by the use of fore-and-aft *B* magnets, athwartship *C* magnets, and quadrantal spheres respectively.

83. Study of adjustment procedure.—Inspection of the general *B*, *C*, and *D* combination of errors, pictured in figure 26, will reveal that there is a definite *isolation* of the deviation effects on cardinal compass headings.

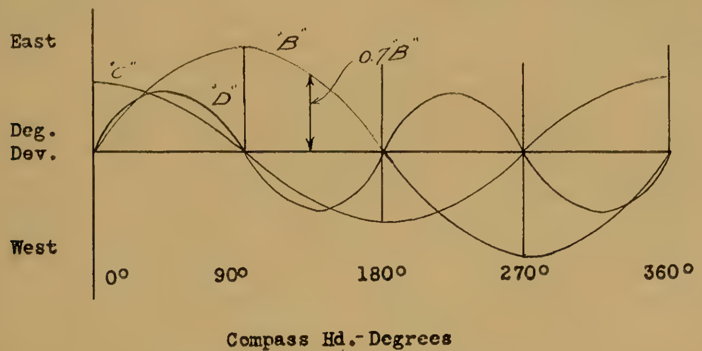


FIGURE 26.—*B*, *C*, and *D* deviation effects.

For example, on 090° or 270° compass headings, the only deviation which is effective is that due to *B*. This isolation, and the fact that the *B* effect is greatest on these two headings, make these headings convenient for *B* correction. A correction of the *B* deviation on a 090° heading will correct the *B* deviation on the 270° heading by the same amount but in the opposite direction; and naturally, it will not change the deviations on the 000° and 180° headings, except where *B* errors are large. However, the total deviation on all the intercardinal headings will be shifted in the same direction as the adjacent 090° or 270° deviation correction, but only by seven-tenths (0.7) of that amount, since the sine of 45° equals 0.707. The same convenient isolation of effects and corrections holds true for the *C* error on 000° and 180° headings; and the correction of *C* error will also change the deviations on all the intercardinal headings by the *seven-tenths rule*, as before. It will now be observed that only after correcting the *B* and *C* errors on the cardinal headings, and consequently their proportional values of the total curve on the intercardinal headings, can the *D* error be observed separately on any of the intercardinal headings. The *D* error may then be corrected by use of the spheres on any intercardinal heading. Correcting *D* error will, as a rule, change the deviations on the intercardinal headings only and not on the cardinal headings. Only when the *D* error is excessive, the spheres are magnetized, or the permanent magnet correctors are so close as to create much induction in the spheres will there be a change in the deviations on cardinal headings as a result of sphere adjustments. Although sphere correction does not generally correct deviations on cardinal headings, it does improve the stability of the compass on the cardinal headings.

84. If it were not for the occasional *A* or *E* errors which exist, the above procedure of adjustment would be quite sufficient; i. e., adjust observed deviations to zero on two adjacent cardinal headings and then on the intermediate intercardinal heading. However, figure 27, showing a combination of *A* and *B* errors, will illustrate why adjusting procedure must include correcting deviations on more than the three essential headings.

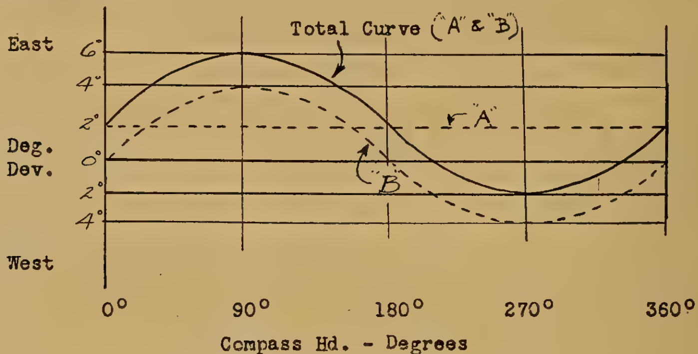


FIGURE 27.—*A* and *B* deviation effects.

If the assumption were made that no *A* error existed in the curve illustrated in figure 27, and the total deviation of 6° E. on the 090° heading were corrected with *B* magnets, the error on the 270° heading would be 4° E. due to *B* over-correction. If then, this 4° E. error were taken out on the 270° heading, the error on the 090° heading would then be 4° E. due to *B* undercorrection. The proper method of eliminating this to-and-fro procedure, and also correcting the *B* error of the ship to the best possible flat curve, would be to split this 4° E. difference, leaving 2° E. deviation on each opposite heading. This would, in effect, correct the *B* error, leaving only the *A* error of 2° E. which must be corrected by other means. It is for this reason that (1) splitting is done between the errors noted on opposite headings, and (2) good adjustments entail checking on all headings rather than on the fundamental three.

85. Before anything further is said about adjustment procedures, it is suggested that care be exercised to avoid moving the wrong corrector. Not only will such practice be a waste of time but it will upset all previous adjustments and calculations. Throughout an adjustment, special care should be taken to pair off spare magnets so that the resultant field about them will be negligible. To make doubly sure that the compass is not affected by stray fields from

them, they should be kept at an appropriate distance until one or more is actually to be inserted into the binnacle.

86. **Adjustment procedures at sea.**—Before proceeding with the adjustment at sea the following precautions should be observed:

(1) Secure all effective magnetic gear in the normal sea-going position.

(2) Make sure the degaussing coils are secured, using the *reversal sequence*, if necessary.

The adjustments are made with the ship on an even keel, swinging from heading to heading *slowly*, and after *steadying* on each heading Chapter V discusses methods of placing a ship on the desired heading.

87. Most adjustments can be made by trial and error, or by routine procedure such as the one presented in chapter I. However, it is more desirable to follow some *analytical* procedure whereby the adjuster is always aware of the magnitude of the errors on all headings as a result of his movement of the different correctors. Two such methods are presented:

(1) A complete deviation curve can be taken for any given condition, and an estimate made of all the approximate coefficients. See chapter IV for methods of making such estimates. From this estimate, the approximate coefficients are established and the appropriate corrections are made with reasonable certainty on a minimum number of headings. If the original deviation curve has deviations greater than 20°, rough adjustments should be made on two adjacent cardinal headings before recording curve data for such analysis. The mechanics of applying correctors are presented in figure 1. A method of tabulating the anticipated deviations after each correction is illustrated in figure 28. The deviation curve used for illustration is the one which was analyzed in chapter IV. Analysis revealed these coefficients:

$$A = 1.0°\text{E.} \quad C = 8.0°\text{E.} \quad E = 1.5°\text{E.}$$
$$B = 12.0°\text{E.} \quad D = 5.0°\text{E.}$$

Heading by compass	1 Original deviation curve	2 Anticipated curve after first correcting A=1.0° E.	3 Anticipated curve after next correcting B=12.0° E.	4 Anticipated curve after next correcting C=8.0° E.	5 Anticipated curve after next correcting D=5.0° E.	6 Anticipated curve after next correcting E=1.5° E.
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	10.5 E.	9.5 E.	9.5 E.	1.5 E.	1.5 E.	0.0
045	20.0 E.	19.0 E.	10.6 E.	5.0 E.	0.0	0.0
090	11.5 E.	10.5 E.	1.5 W.	1.5 W.	1.5 W.	0.0
135	1.2 W.	2.2 W.	10.6 W.	5.0 W.	0.0	0.0
180	5.5 W.	6.5 W.	6.5 W.	1.5 E.	1.5 E.	0.0
225	8.0 W.	9.0 W.	0.6 W.	5.0 E.	0.0	0.0
270	12.5 W.	13.5 W.	1.5 W.	1.5 W.	1.5 W.	0.0
315	6.8 W.	7.8 W.	0.6 E.	5.0 W.	0.0	0.0

FIGURE 28.—Tabulating anticipated deviations—Analysis method.

(2) More often it is desirable to begin adjustment immediately, eliminating the original swing for deviations and the estimate of approximate coefficients. In this case the above problem would be solved by tabulating data and anticipating deviation changes as the corrections are made. Figure 29 illustrates such procedure. It will be noted that a new column of values is started after each change is made. This method of tabulation enables the adjuster to calculate the new residual deviations each time a corrector is changed, so that a record of deviations is available at all times during the swing. Arrows are used to indicate where each change is made.

Heading	First observation	Observed deviations after correcting B=11.5° E.	Anticipated deviations after correcting C=8.0° E.	Anticipated deviations after correcting D=5.0° E.	Anticipated deviations after correcting A=1.0° E.	Anticipated deviations after correcting E=1.5° E.
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	------------	10.5 E.→	2.5 E.	2.5 E.	1.5 E.	0.0
045	------------	------------	6.4 E.→	1.4 E.→	0.4 E.	0.4 E.
090	11.5 E.→	0.0	0.0	0.0	1.0 W.→	0.5 E.
135	------------	9.2 W.	3.6 W.	1.4 E.	0.4 E.	0.4 E.
180	------------	5.5 W.	2.5 E.	2.5 E.	1.5 E.	0.0
225	------------	0.0	5.6 E.	0.6 E.	0.4 W.	0.4 W.
270	------------	1.0 W.	1.0 W.	1.0 W.	2.0 W.	0.5 W.
315	------------	1.2 E.	4.4 W.	0.6 E.	0.4 W.	0.4 W.

Figure 29.—Tabulating anticipated deviations—One-swing method.

Since the B error is generally greatest, it is corrected first; hence on a 090° heading the 11.5° E. deviation is corrected to approximately zero by using fore-and-aft B magnets. A lot of time need not be spent trying to reduce this deviation to exactly zero since the B coefficient may not be exactly 11.5° E., and some splitting might be desirable later. After correcting on the 090° heading, the swing would then be continued to 135° where a 9.2° W. error would be observed. This deviation is recorded, but no correction is made because the quadrantal error is best corrected after the deviations on all four cardinal headings have been corrected. The deviation on the 180° heading would be observed as 5.5° W. Since this deviation is not too large and splitting may be necessary later, it need not be corrected at this time. Continuing the swing to 225°, 0.0° deviation would be observed and recorded. On the 270° heading the observed error would be 1.0° W., which is compared with 0.0° deviation on the opposite 090° heading. This could be split, leaving 0.5° W. deviation on both 090° and 270°, but since this is so small it may be left. On 315° the observed deviation would be 1.2° E. At 000°, a deviation of 10.5° E. would be observed and compared with 5.5° W. on 180°. Analysis of the deviations on 000° and 180° headings reveals an 8.0° E. *C* error, which should then be corrected with athwartship *C* magnets leaving 2.5° E. deviation on both the 000° and 180° headings. All the deviations in column two are now re-calculated on the basis of such an adjustment at 000° heading and entered in column three. Continuing the swing, the deviation on 045° would then be noted as 6.4° E. Knowing the deviations on all intercardinal headings, it is now possible to estimate the approximate coefficient *D*. *D* is 5.0° E. so the 6.4° E. deviation on 045° is corrected to 1.4° E. and new anticipated values are recorded in a new column. This anticipates a fairly good curve, an estimate of which reveals, in addition to the *B* of 0.5° E. which was not considered large enough to warrant correction, an *A* of 1.0° E and an *E* of 1.5° E. These *A* and *E* errors may or may not be corrected, as practical. If they are corrected, the subsequent steps would be as indicated in the last two columns. It will be noted that the ship has made only one swing, all corrections have been made, and some idea of the expected curve is available.

88. Should the spheres be magnetized, or the permanent *B* and *C* magnets be very close to the spheres, any movement of the spheres will change the *B* and *C* errors on the compass necessitating readjustment of the *B* and *C* corrector magnets.

Inasmuch as the spheres contribute somewhat to the heeling correction, and the dip needle method of heeling magnet adjustment at dock-side has certain inaccuracies, it would be desirable, if possible, to *refine* the heeling adjustment under rolling conditions while the ship is on north and south headings. (See chapter XV.) Radical changes in the position of this heeling magnet, with Flinders bar present, may change the deviation curve because of its induction effects on the Flinders bar; and readjustment of the fore-and-aft *B* magnets may be necessary.

Chapter VIII discusses other *interaction effects* between the various correctors.

89. **Deviation curves.**—The last step, after either of the above methods of adjustment, is to *secure all correctors in position* and to *swing for residual deviations*. These residual deviations are for *undergaussed conditions* of the ship, and they should be recorded, along with details of corrector positions, on the standard Navy Form NBS 1104 and in the *Compass Record Book*, NBS 1101. Article 132 discusses the purposes of the various NBS Record Forms more fully.

NAVSHIPS (250)
NBS 1104
Rev. (11-43)

MAGNETIC COMPASS TABLE

U. S. S. FLASH No. AP 999 (BB, PC, ETC.)

ST'D ☒ STEERING ☐ OTHER

Binnacle Type: Navy St'd/~~wood~~/~~other~~ MK. VII

Compass 7½ " Make Ritchie No. 3520

Type CC Coils "G" Date 1 Jan. 1944

SHIPS HD. BY COMPASS	DEVIATIONS		SHIPS HD. BY COMPASS	DEVIATIONS	
	DG OFF	DG ON		DG OFF	DG ON
0	1.0°W		**180**	1.0°E	
15		For Degaussing, see Chapter XI	195		For Degaussing, see Chapter XI
30			210		
45	0.5°W		**225**	0.5E	
60			240		
75			255		
90	0.0°		**270**	0.0°	
105			285		
120			300		
135	0.5°E		**315**	0.5°W	
150			330		
165			345		

~~CYCLE/DO NOT~~ CYCLE DG COILS WHEN SECURING

4 Alnico RED ~~FORE~~/AFT AT AVERAGE DISTANCE 13.1 " FROM CARD

2 Alnico RED PORT/~~STBD~~ AT AVERAGE DISTANCE 15.7 " FROM CARD

2 - 7" SPHERES AT 13.5 " λ= 0.82 ~~ROUGH~~/GOOD/~~EXACT~~

HEELING MAGNET RED/~~BLUE~~ UP 15.5 " FROM COMPASS CARD

12 " OF BAR FORWARD/~~AFT~~ H= 0.190 Z= +0.530

Note: 3" gun forward of compass must be trained fore-and-aft.

SIGNED ______ ADJUSTOR.

SUBMITTED Lt. John Doe NAVIGATOR.

APPROVED Comdr. B. A. Mann COMMANDING.

10—37280-1

(FRONT)

INSTRUCTIONS

1. This form shall be filled out by the adjustor (if available) or the navigator, one for each magnetic compass, as follows:
   - *a.* After each normal adjustment of the magnetic compasses.
   - *b.* After each degaussing compass compensation coil adjustment.
   - *c.* Each time the vessel crosses the magnetic equator.
   - *d.* As of 30 June each year if it has not already been submitted, as above, during the previous 12 months.

2. When the "DG ON" curve is taken, the degaussing coils must be set to the proper value for latitude and heading as specified in DGP 40 series in the Degaussing Folder.

3. Each time the form is filled out, a copy is to be sent to BuShips.

4. The adjustor should determine whether the MFQ coils should be cycled when securing and so indicate on the form.

5. The first time this report is filled out for a given compass, the following performance data should be included:
   - *a.* Compass steady/~~unsteady~~ at sea.
   - *b.* ~~Compass slow/sluggish/sticky.~~
   - *c.* Deviations ~~change~~/remain reliable.
   - *d.* Sweeping operations do/do not create unreliable deviations.
   - *e.* Degaussed deviations ~~do~~/do not vary.
   - *f.* Overhauls, gunfire, flashing, wiping, deperming, with dates and effect on magnetic compass.

6. On subsequent submissions of this report enter only performance data (par. 5) which has changed from that reported on the previous report, or which is seriously affecting the magnetic compass.

7. This report supersedes NBS 1102, 1104, 1106, 1107, and CC-2.

RECORD BELOW DATA FROM BOTH SIDES OF PREVIOUS NBS 1104 ALSO DEVIATIONS BEFORE THIS READJUSTMENT

DATE	H	Z	DEV. BY COMPASS		BAR (FORE / AFT)	BY Z LOOP	CALCULATED	ROUGH	OTHER
			090	270					
7/5/43	.32	.00	0°	0°	☐ 0" ☐			X	
1/1/44	.19	+.53	9.0°E	9.0°W	☐ 0" ☐				obs.
1/1/44	.19	+.53	0°	0°	☒ 12" ☐		X		
					☐ " ☐				
					☐ " ☐				
					☐ " ☐				
					☐ " ☐				

U. S. GOVERNMENT PRINTING OFFICE 16—37230-1

(BACK)

FIGURE 30.—Deviation table—Form NBS 1104.

Navy Form NBS 1104 is complete and desirable in the interest of improved Flinders bar correction and shielding conditions. Navy Form NBS 1105 may be used for posting deviations at the binnacle. Figure 30 illustrates both sides of form NBS 1104, with proper instructions and sample deviation and Flinders bar data. Should the ship be equipped with degaussing coils, a swing for residual deviations under *degaussed conditions* should also be made and data recorded as indicated in chapter XI.

On these swings extreme care should be exercised in taking bearings or azimuths and in steadying down on each heading since this swing is the basis of standard data for that particular compass. If there are any peculiar changeable errors, such as movable guns, listing of the ship, or anticipated decay from deperming, which would effect the *reliability* of the compass, they should also be noted on the deviation card at this time. Chapter IX discusses these many sources of error in detail.

If the Flinders bar adjustment is not based on accurate data, as with a new ship, it would be well to exercise particular care in recording the conventional *Daily Compass Log* data during the first cruise on which a considerable change of magnetic latitude occurs.

90. In order to have a reliable and up-to-date deviation card at all times it is suggested that the ship be swung to *check compass deviations* and *to make readjustments*, if necessary, after:

(1) Radical changes in magnetic latitude.

(2) Deperming, flashing, or wiping. (Delay adjustment several days, if possible, after such treatment.)

(3) Structural changes.

(4) Long cruises or docking on the same heading such that the permanent magnetic condition of the vessel has changed.

(5) Magnetic equipment near the binnacle has been altered.

(6) Reaching the magnetic equator, in order to acquire Flinders bar data. (See ch. VIII.)

(7) Every 3 months, to account for magnetic decay, etc.

(8) Appreciable change of heeling magnet position if Flinders bar is present.

(9) Readjustment of any corrector.

(10) Change of magnetic cargo.

(11) Commissioning.

With such reasonable care, the compass should be a reliable instrument requiring little attention except for occasional refinements of the heeling magnet position as the ship changes magnetic latitude.

CHAPTER VIII. CORRECTOR EFFECTS—INTERACTIONS BETWEEN CORRECTORS

91. Until now the principles of compass adjustment have been considered from a *qualitative* point of view. In general this is quite sufficient since the correctors need merely be moved until the desired amount of correction is obtained. However, it is often valuable to know the *quantitative* effects of different correctors as well as their qualitative effects. Furthermore, as has been stated previously, all the correctors are not completely independent of each other. *Interaction* results from the proximity of the permanent magnet correctors to the soft iron correctors, with appreciable induction effects in the latter. Consequently any shift in the relative position of the various correctors will change their interaction effects as well as their separate correction effects. Additional inductions exist in the soft iron correctors from the magnetic needles of the compass itself. The adjuster should therefore be familiar with the nature of these interactions so as to evolve the best methods of adjustment.

92. Quadrantal sphere correction.—Figure 31 presents the approximate *quadrantal correction* available with different sizes of spheres,

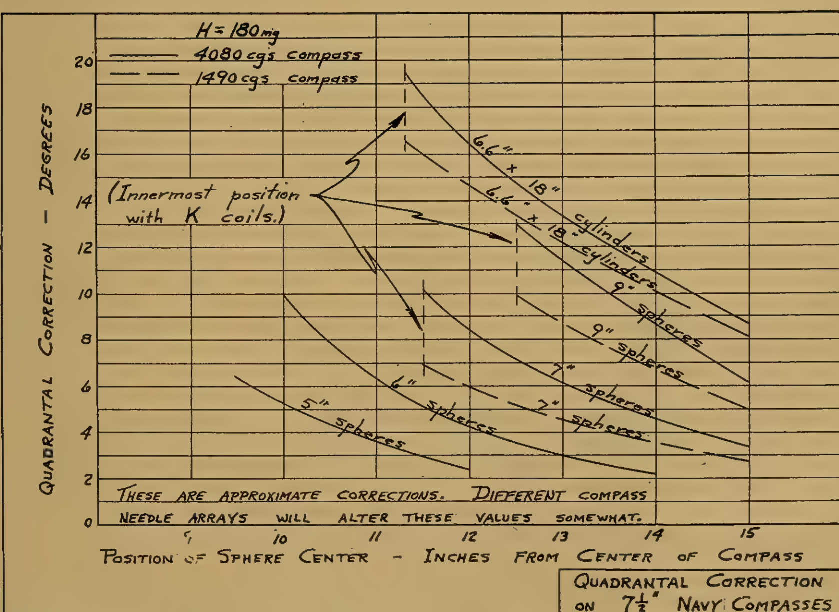


FIGURE 31.

at various positions on the sphere brackets, and with different magnetic moment compasses. These quadrantal corrections apply whether the spheres are used as D, E, or combination D and E correctors. Quadrantal correction from spheres is due partially to *earth's field induction* and partially to *compass needle induction.* Since compass needle induction does not change with magnetic latitude, and earth's field induction does, the sphere correction is not constant for all magnetic latitudes. A reduction in the percentage of needle induction in the spheres to the earth's field induction in the spheres will improve the constancy of sphere correction over all magnetic latitudes. Such a reduction in the percentage of needle induction may be obtained by:

(1) Utilizing a low magnetic moment compass. See article 102.

(2) Utilizing special spheroidal-shaped correctors, placed with their major axes perpendicular to their axis of position.

(3) Using larger spheres farther away from the compass.

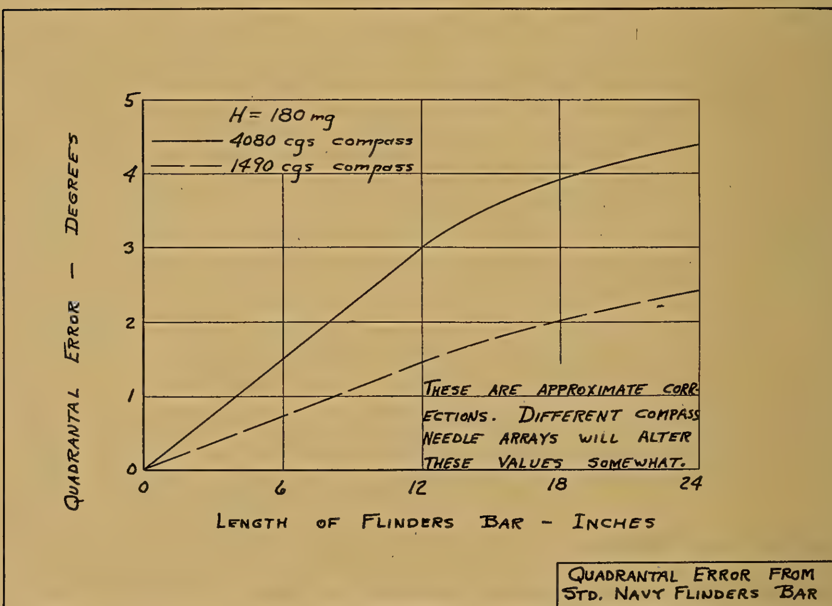


Figure 32.

93. Quadrantal error from Flinders bar.—Figure 32 presents the approximate *quadrantal error* introduced by the presence of Standard Navy Flinders bar. Since the Flinders bar is generally placed in the forward or aft position, it acts as a small minus D corrector, as well as a corrector for vertical induced effects. This means that upon inserting Flinders bar in such a position, the regular spheres should be moved closer to correct for the increased plus D error, or vice versa, if Flinders bar is removed. This D error in the Flinders bar is due mostly to compass needle induction since the bar is small in cross-section and is close to the compass. Since such needle induction is practically constant, the deviation effects on the compass will change with magnetic latitudes because the directive force, H, changes. However, when balanced by sphere correctors this is advantageous because it tends to cancel out the variable part of the sphere correction which is due to the compass needle induction.

94. Slewing of spheres.—Figure 33 is a convenient chart for determining the proper *slewed position for spheres.* The total values of the D and E quadrantal coefficients are used on the chart to locate a

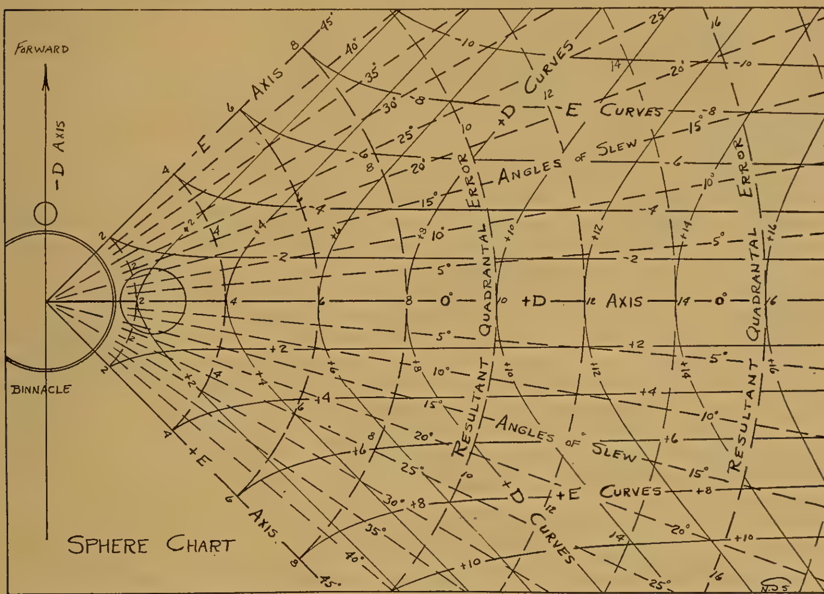


FIGURE 33.

point of intersection. This point directly locates the angle and direction of slew for the spheres on the illustrated binnacle. This point will also indicate, on the radial scale, the resultant amount of quadrantal correction required from the spheres in the new slewed position to correct for both the D and E coefficients. The total D and E coefficients may be calculated by an analysis of deviations on the uncorrected binnacle, or by summarizing the uncorrected coefficients with those already corrected. The data in figures 31 and 32 will be useful in either procedure. For further information concerning slewing of spheres see article 139.

Example: A ship having a Navy Standard binnacle, with 7″ spheres at 13″ position athwartship and 12″ Flinders bar forward, is being swung for adjustment. It is observed that there exist 4° E. D error and 6° E. E error with the spheres in their existing positions. Since the spheres are athwartship, the total E coefficient for the ship is 6° E., as observed. Figure 31 indicates that the spheres in their present position are correcting 6° E. D error, hence the total D coefficient of the ship and Flinders bar is 10° E. Figure 33 indicates that 6° E. E and 10° E. D coefficients require slewing the spheres 15½° clockwise from their present athwartship position. The resultant quadrantal error is indicated as 11.7°. Figure 31 indicates that the 7″ spheres should then be moved to the 11″ position after slewing 15½° clockwise so as to correct both the D and E errors. Use of this chart will eliminate mathematical or trial-and-error methods of adjustment for quadrantal errors, as well as quickly provide information for physically moving the spheres.

95. Flinders bar adjustment.—As has previously been stated in chapter VII, it is generally impossible to place the correct amount of Flinders bar without *reliable data* obtained in two widely separated magnetic latitudes. The placing of Flinders bar by the use of an empirical amount, or by an inspection of the ship's structures, is merely an approximation method and refinements will usually be necessary when data is obtained. There are several methods of acquiring and utilizing such latitude data in order to determine the proper amount of Flinders bar, hence an elaboration on the following items:

(1) The data necessary for calculation of Flinders bar length, and the conditions under which this data should be acquired.

(2) The best method of utilizing such data to determine the proper length of Flinders bar.

96. Data required for Flinders bar adjustment.—The data required for correct Flinders bar adjustment consists of accurate tables of deviations with details of corrector conditions at two different magnetic latitudes, the farther apart the better. See figure 30 for example of how such data is recorded on NBS Form 1104. Should it be impossible to swing ship for a complete table of deviations, the deviations on east and west *magnetic* headings would be helpful. On many occasions ship's log data is available, but is of little use for Flinders bar calculation because it is not reliable. The following precautions should be observed when such data is to be taken in order to assure that observed deviation changes are due only to changes in the H and Z components of the earth's field.

(1) Degaussing should be secured, by a reversal process if necessary, at both latitudes before data is taken.

(2) If the ship has been docked or steaming on one heading for several days prior to the taking of these data, the resulting temporary magnetism (Gaussin error) would create erroneous devia-

tions. A sort of shake-down on other headings prior to taking data would reduce such errors.

(3) Deperming, structural changes, heavy gunfire, magnetic cargoes, etc., subsequent to the first set of data will make the comparative results meaningless.

(4) Inasmuch as the data will not be reliable if the ship's permanent magnetism changes between the two latitudes, it will likewise be unreliable if any of the binnacle correctors are changed, including the heeling magnet.

In the event that an intelligent approximation as to Flinders bar length cannot be made, then the deviations at the two latitudes should be taken with no Flinders bar in the holder. This procedure would also simplify the resulting calculations.

97. Methods of determining Flinders bar length.

(1) Having obtained reliable deviation data at two different magnetic latitudes, the changes in the deviations, if any, may justifiably be attributed to an incorrect Flinder's bar adjustment. E./W. and N./S. deviations are the ones which are subject to major changes from such an incorrect adjustment. If there is no change in any of these deviations, the Flinders bar adjustment is probably correct. A change in the E./W. deviations indicates an unsymmetrical arrangement of vertical iron forward or aft of the compass, which requires correction by Flinders bar, forward or aft of the compass. A change in the N./S. deviations indicates an unsymmetrical arrangement of vertical iron to port or starboard of the compass, which requires correction by Flinders bar to port or starboard of the compass. This latter case is very rare, but can be corrected, as indicated in chapter XVIII.

Determine the B deviations on *magnetic* east/west headings at both latitudes. The constant c may then be calculated from the following formula:

$$c=\lambda\left[\frac{H_1 \tan B_1 - H_2 \tan B_2}{Z_1 - Z_2}\right]$$

where

λ =shielding factor (0.7 to 1.0 average).
H_1=earth's field, H, at 1st latitude.
B_1=degrees B deviation at 1st latitude (magnetic headings).
Z_1=earth's field, Z, at 1st latitude.
H_2=earth's field, H, at 2d latitude.
B_2=degrees B deviation at 2d latitude (magnetic headings).
Z_2=earth's field, Z, at 2d latitude.

This constant c represents a resultant mass of vertical iron in the ship which requires Flinders bar correction. If Flinders bar is present at the time of calculations, it must be remembered that it is already correcting an amount of c in the ship (see figure 34 (b)) which must be added to the uncorrected c, calculated by the above formula. This *total* value of c, is used in conjunction with figure 34 (b) to indicate directly the necessary *total* amount of Flinders bar. If this total c is negative, Flinders bar is required on the forward side of the binnacle; and if it is positive, Flinders bar is required on the aft side of the binnacle. The iron

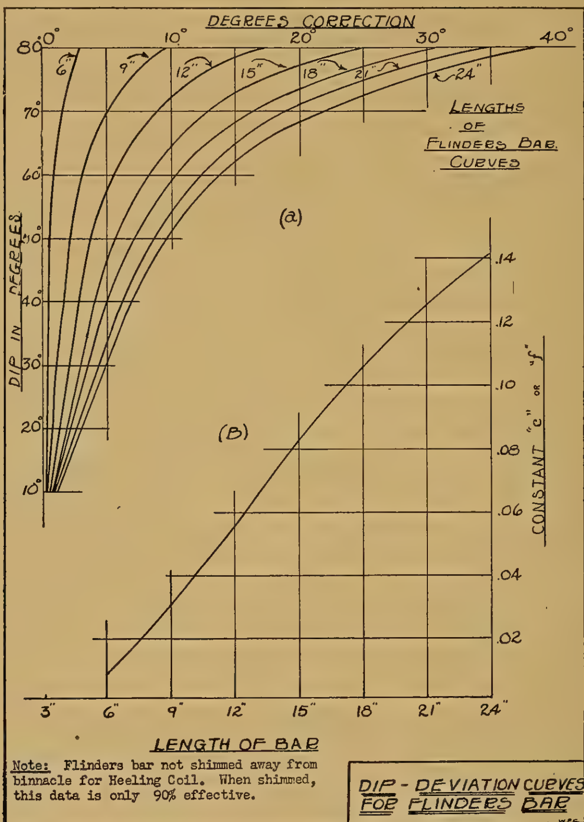


FIGURE 34.

sections of Flinders bar should be *continuous* and *at the top* of the tube with the longest section at the top. Wooden spacers are used at the bottom of the tube to achieve such spacing. See problem 6 in the appendix for solution of a typical problem. It will be noted that the B deviations used in this formula are based on data on E./W. *magnetic* headings rather than on compass headings, as with the approximate coefficients. The Napier's diagram will assist in conversion of data from compass headings to magnetic headings, if necessary.

(2) Should the exact amount of correction required for vertical induction in the ship at some particular magnetic dip, θ, be known, figure 34 (a) will directly indicate the correct amount of Flinders bar to be placed at the top of the holder. The exact amount of correction would be known when one of the latitudes is the magnetic equator, and the deviations there are negligible. Then the *B* deviation in degrees on magnetic headings at the other latitude is the exact amount to correct by means of curves in figure 34 (a).

(3) Lord Kelvin's rule for *improving* the Flinders bar setting is: "Correct the deviations observed on east or west courses by the use of fore-and-aft *B* magnets when the ship has arrived at places of weaker vertical magnetic field, and by the use of Flinders bar when she has arrived at places of stronger vertical magnetic field, whether in the northern or southern hemisphere."

98. After determining the correct amount of Flinders bar by either method (1) or (2) above, the bar should then be inserted at the top of the holder and the fore-and-aft *B* magnets readjusted to correct the remaining *B* error. Sphere adjustments should likewise be refined.

It is quite possible that on inserting the Flinders bar, no visible deflection of the compass will be observed, even on an east or west heading. This should cause no concern because certain additional induction effects exist in the bar from:

(1) The heeling magnet.

(2) The existing fore-and-aft *B* magnets.

(3) The vertical component of the ship's permanent magnetic field.

99. A common, but inaccurate, method of determining the approximate Flinders bar length is the so-called *10° method.* By this method, Flinders bar is added on an east or west magnetic heading until all deviation but 10° is visibly removed. This method erroneously assumes that the deviations due to fore-and-aft permanent magnetism are always 10°, regardless of compass location, structure, perm conditions, class of ship, or different directive forces on the compass.

Inasmuch as there are so many extraneous induction effects in the Flinders bar, it is likewise stressed that the *drop-in method* of determining Flinders bar, is invalid. By this method, the amount of *B* deviation due to vertical induction in the ship at the latitude of adjustment would be calculated, and the Flinders bar would be then adjusted on an east or west heading until a visible deflection equal to this amount of *B* deviation was observed on the compass. Even though this adjustment is made with the heeling magnet removed, it is now obvious that other induction effects are introduced into the Flinders bar, in addition to the induction from the earth's vertical field. These additional induction effects may increase or decrease the apparent correction effect of the Flinders bar, hence there is no simple correlation between the length of Flinders bar and its visible deviation effect on the compass. Likewise, any amount of permanent magnetism in the Flinders bar will further distort the relation between the length of bar and its visible deviation effect on the compass. These other induction effects cannot always be removed for such adjustments, as can the heeling magnet, because the vertical permanent field is fixed with the ship, and the removal of the fore-and-aft *B* magnets would destroy the directive force on the compass.

100. Heeling magnet induction in Flinders bar.—Figure 35 presents typical induction effects in the Flinders bar for different posi-

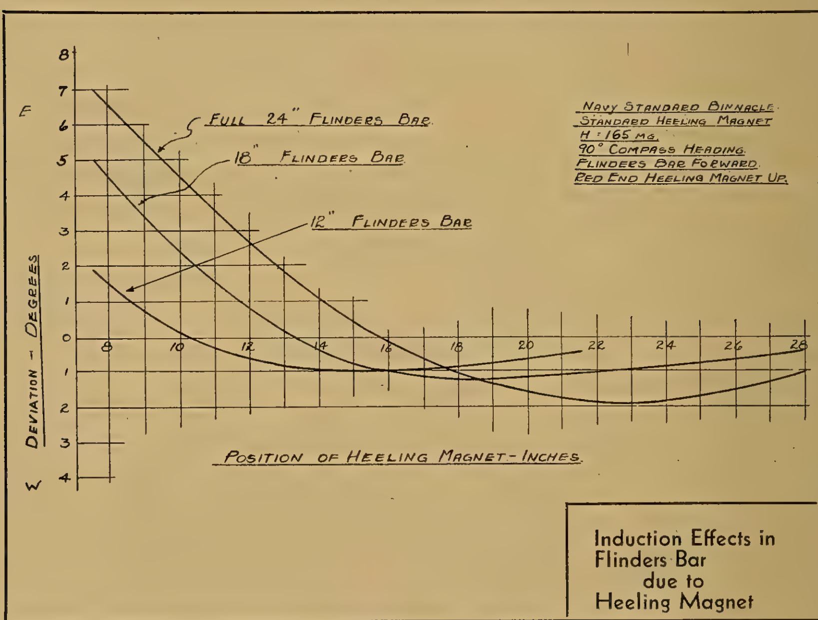
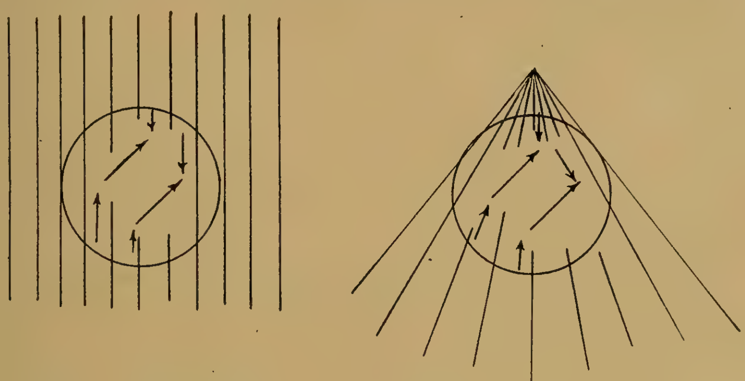


FIGURE 35.

tions of heeling magnet. An adjuster familiar with the nature of these effects will appreciate the advantages of establishing the Flinders bar and heeling magnet combination before leaving dockside. Deviations must also be checked after adjusting the heeling magnet, if Flinders bar is present.

101. Corrector magnet inductions in spheres.—Should a ship have spheres and many permanent *B* and *C* magnet correctors close to the compass, there will be a condition of induction existing between these correctors which will require some shuttling back and forth between headings while making adjustments. This situation can be improved by using larger spheres further out, and by approximately setting the spheres before starting adjustments, as well as by using more magnets further from the spheres and compass. Magnetized spheres, as well as magnetized Flinders bar, will not only cause some difficulty during adjustment, but might introduce an unstable deviation curve if they should undergo a shake-down or change of magnetic condition.

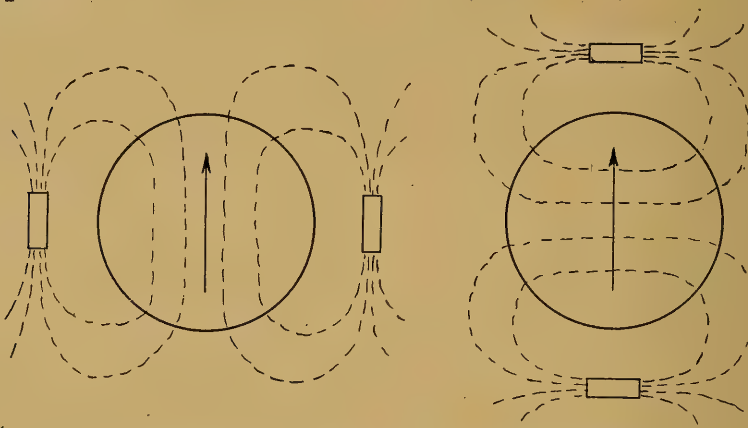
102. Compasses.—Compasses themselves play a very important part in compass adjustment, although it is common belief that the compass is only an indicating instrument, aligning itself in the resultant magnetic field. This would be essentially true if the magnetic fields were uniform about the compass; but unfortunately magnetism close to the compass imposes *nonuniform fields* across the needles. In other words, adjustment and compensation sometimes employ nonuniform fields to correct uniform fields. Figure 36 indicates the dif-



Uniform magnetic field (balanced torques). Nonuniform magnetic field (unbalanced torques).

FIGURE 36.—Magnetic fields across compass needle arrays.

ference between uniform and nonuniform field effects on a compass. Such unbalanced torques, arising from nonuniform magnetic fields, create deviations of the compass which have higher frequency characteristics. Compass designs include many combinations of different length needles, different number of needles, and different spacings and arrangements of needles—all designed to minimize the higher order deviations resulting from such nonuniform magnetic fields. Although compass design is rather successful in minimizing such deviations, it is obvious that different compasses will be affected differently by the same magnetic fields. It is further stressed that, even with proper compass design, it is the duty of all adjusters to exercise care in applying correctors in order to create the most uniform magnetic field possible. This is the basis for the rule which requires the use of strong correctors symmetrically arranged as far away from the compass as possible, instead of weak correctors very close to the compass. In general it is better to use larger spheres placed at the extremities of the brackets, equally distant from the center of the compass. *B* and *C* permanent magnet correctors should always be placed so as to have an equal number of magnets on both sides of the compass where possible. They should also be centered as indicated in figure 37, if regular tray arrangements are not available. The desire for symmetrical magnetic fields is one reason for maintaining a sphere of specified radius, commonly called *the magnetic circle*, about the magnetic compass location. This circle is kept free of any magnetic or electrical equipment.



B magnet fields. *C* magnet fields.

FIGURE 37.—Arrangements of corrector magnets.

The *magnetic moment* of the compass needle array is another factor in compass design which ranks in importance with the proper arrangement of needles. This magnetic moment controls the needle induction in the soft iron correctors, as discussed in articles 92 and 93, and hence governs the constancy of those corrector effects with changes in magnetic latitude. The 7½″ Navy No. 1 alcohol-water compass has a magnetic moment of approximately 4000 cgs units, whereas the 7½″ Navy No. 1 oil compass has a magnetic moment of approximately 1650 cgs units. The lower magnetic moment compass allows considerably less change in quadrantal correction, although the periods are essentially comparable because of the difference in the compass fluid characteristics.

Other factors which must be considered in compass design are period, fluid, swirl, vibration, illumination, tilt, pivot friction, fluid expansion, etc. These factors, however, are less important from an adjustor's point of view than the magnetic moment and arrangement of needles, and are therefore not discussed further in this text.

CHAPTER IX. TRANSIENT DEVIATIONS OF THE MAGNETIC COMPASS

103. Stability.—The general treatise on compass adjustment concerns itself only with the principles of *steady-state magnetism;* i. e., the effects of permanent and induced magnetism and their appropriate correctors. This knowledge, along with the ability to handle sun's azimuth and ship's heading, is the backbone of compass adjustment. However, a correction may be very carefully and accurately made and still prove disastrous to the ship; for example, a compass may have a perfect deviation curve, but when a nearby gun is trained the magnetic effects on the compass are changed. Although a compass adjuster cannot place correctors on the binnacle for such variable effects, it is definitely his duty to recognize and handle them in the best possible manner. If it is impossible to eliminate the source of trouble, or impractical to relocate the binnacle, the details of alignment or excitation of the sources of error should be specified on the deviation card. With such information, the navigator would know when or when not to rely on his magnetic compass. In other words, a good adjuster should not only provide a good deviation curve which is reliable under specifically stated conditions, but also point out and record probable causes of unreliability which cannot be eliminated.

104. Sources of transient error.—The *magnetic circle* about the magnetic compass is intended to reduce such *transient* conditions, but there still are many items, both electrical and magnetic, which cause erratic effects on the compass. The following list is presented to assist in the detection of such items. If in doubt, a test can be made by swinging any movable object or energizing any electrical unit while observing the compass for deviations. This would best be tried on two different headings, 90° apart, since the compass might possibly be affected on one heading and not on the other.

1. Some magnetic items which cause variable deviations if placed too close to the compass are as follows:

(*a*) Guns on movable mounts.
(*b*) Ready ammunition boxes.
(*c*) Variable quantities of ammunition in ready boxes.
(*d*) Magnetic cargo.
(*e*) Hoisting booms.
(*f*) Cable reels.

(*g*) Metal doors in wheelhouse.
(*h*) Chart table drawers.
(*i*) Movable gyro repeater.
(*j*) Windows and ports.
(*k*) Signal pistols racked near compass.
(*l*) Sound powered telephones.
(*m*) Magnetic wheel or rudder mechanism.
(*n*) Knives or ash trays near binnacle.
(*o*) Watches, wrist bands, spectacle frames.
(*p*) Hat grommets, belt buckles, metal pencils.
(*q*) Heating of smoke stack, or exhaust pipes.
(*r*) Landing boats.

2. Some electrical items which cause variable deviations if placed too close to the compass are as follows:

(*a*) Electric motors.
(*b*) Magnetic controllers.
(*c*) Gyro repeaters.
(*d*) Nonmarried conductors.
(*e*) Loud speakers.
(*f*) Electric indicators.
(*g*) Electric welding.
(*h*) Large power circuits.
(*i*) Searchlights.
(*j*) Electrical control panels or switches.
(*k*) Telephone headsets.
(*l*) Wind shield wipers.
(*m*) Rudder position indicators, solenoid type.
(*n*) Minesweeping power circuits.
(*o*) Engine room telegraphs.
(*p*) Radar equipment.
(*q*) Magnetically controlled switches.
(*r*) Radio transmitters.
(*s*) Radio receivers.
(*t*) Voltage regulators.

105. There is another source of transient deviation trouble known as the *Gaussin error.* This error results from the tendency of a ship's structures to retain some of their induced magnetic effects for short periods of time. For example, a ship travelling north for several days, especially if pounding in heavy seas, will tend to retain some fore-and-aft magnetism hammered in under these conditions of induction. Although this effect is not too large and generally decays within a few hours, it may cause incorrect observations or adjustments, if neglected. This same type of error occurs when ships are docked on one heading for long periods of time. A short shakedown with the ship on other headings will tend to remove such errors. A similar sort of residual magnetism is left in many ships if the degaussing circuits are not secured by the reversal sequence, as discussed in article 128.

106. *Deperming*, *flashing*, or *wiping* will change the magnetic condition of the vessel and therefore necessitate readjustment of compass errors. The decaying effects of deperming are sometimes very rapid, therefore it is best to delay readjustment for several days after such treatment. Since the magnetic fields used for such treatments are sometimes rather large at the compass locations, the Flinders bar, compass, and such related equipment is sometimes removed from the ship during these operations.

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Part II.—DEGAUSSING COMPENSATION

CHAPTER X. PROCEDURES FOR DEGAUSSING COMPASS COMPENSATION (CHECK-OFF LIST)

NOTE.—If the coil installation or compensation necessitates changing any of the magnetic correctors, the magnetic adjustment should be checked. Refer to chapter I. Extreme care is essential in making the coil compensation so as to avoid magnetizing the Flinders bar or spheres.

107. A. Dockside tests.

1. Physical checks of binnacle and coils:
   - (*a*) Magnetization check of spheres and Flinders bar (art. 74).
   - (*b*) See that spheres are in correct position (art. 78).
   - (*c*) See that correct length of Flinders bar is in holder (arts. 77 and 95 to 99 inclusive).
   - (*d*) Flinders bar coil must be mounted high and securely.
   - (*e*) Sphere coil alignments and mechanical security.
   - (*f*) "G", "K", or "T" coil alignments and mechanical security.
   - (*g*) Watertightness of coil wiring.
   - (*h*) See that all fittings are nonmagnetic.
2. Electrical checks on control boxes and compass coils:
   - (*a*) Check each coil for continuity of circuit.
   - (*b*) Check each set of coil leads for identity, and tag, by:
     - (1) Visual wiring check.
     - (2) Ohmmeter test (art. 129).
     - (3) Battery and compass test. (Use flashlight battery to energize a coil and explore for effective coil with small compass).
   - (*c*) Check that series coil windings are not bucking.
   - (*d*) Check each coil for insulation resistance to ground and to all other coils.
   - (*e*) Connect proper group of coil windings to each compass coil box (art. 120).
   - (*f*) Check that control boxes are watertight. (Terminal tubes, packing gaskets, etc.; 5 pounds per square inch air pressure may be used.)

3. Check on degaussing system:
   - (*a*) Accuracy of prints of coil installation.
   - (*b*) Check that connection of compass coils to the degaussing system will provide a voltage at the control box for each effective degaussing coil (art. 121). These voltages must be:
     - (1) Proportional to the degaussing coil effect.
     - (2) Reversing with the degaussing circuits.
   - (*c*) Check that leads from each degaussing coil to its compass control box are correct, and tag.
   - (*d*) Check each degaussing coil insulation resistance to ground and to all other degaussing coils.
   - (*e*) Insure that sufficient compensating coil circuits are provided for all effective degaussing coils.
   - (*f*) Note whether compass returns to original reading after each degaussing coil had been energized and secured. Try reversal sequence (art. 128).
   - (*g*) Obtain range instructions, if available, for zone and maximum degaussing coil current settings (ship's degaussing folder).

108. B. Dockside compensation.—(*Compensation is best made with the coils heated to their operating conditions. If any coil requires securing by reversals, it should be so secured each time during the process of compensation. Record the compensation data on CC–1 forms as it is taken. See art. 126.*)

1. Heeling coil procedure. (*For any type compass coil installation*):
   - (*a*) Remove compass and balance dip needle in approximate location of compass needles, with all degaussing coils secured. In the case of the Model "B" magnesyn transmitter employing the special mounting bracket, the dip needle should be carefully placed at a height of 2⅝″ above the mounting plate. For Model "A" magnesyn transmitter this distance should be 2⅜″.
   - (*b*) Energize M degaussing coil to *maximum operating* current and note unbalance of the dip needle.
   - (*c*) Adjust current in the H–M (Heeling) compass coil until balance of dip needle is restored. If needle is further unbalanced by increasing the H–M coil current, the H–M coil polarity must be reversed. (*Coarse current adjustment is achieved by placing*

the H–M slide wire resistor at the midposition and cautiously shorting out sections of series resistance in the H–M control circuit. The refined adjustment is then obtained by revising the setting of the H–M slide wire resistor. See art. 119).

(*d*) Be sure that final setting *would not permit* more than 1.4 amperes (1.0 amperes for "T" coils) to flow through the variable control resistor, at *maximum* degaussing coil current. This is approximately equivalent to 2.2 volts per winding across H–M compass coils of the type "B," "G," or "K" installation, and 4.8 volts per winding across the H–M compass coils of the type "T" installation. If fixed resistors are in series with variable resistor, maximum currents are smaller, as shown in chapter XII.

(*e*) Repeat (*b*), (*c*), and (*d*) for all other degaussing coils (F, Q, A) individually, while dip needle is still balanced. Correct each with H–F, H–Q, and H–A coil windings, respectively.

2. Type "B" compensating coil procedures. (*Cardinally mounted type "T" coil procedure is the same, except for voltage limitations as noted in art. 129. Heeling adjustments for any type coils are made as in Section B–1 of this Check-off list*) :

(*a*) Replace dip needle with regular compass.

(*b*) Deflect compass card to 090° or 270° heading, whichever is closer, with all degaussing coils secured (art. 125).

(*c*) Energize M degaussing coil to *maximum operating* current, and note deviation of the compass. (See note at end of art. 108.)

(*d*) Adjust current in the B–M (Flinders bar) compass coil until compass returns to original position. If the compass is further deviated by increasing the B–M coil current, the B–M coil polarity must be reversed. (*Coarse and fine adjustments are achieved as noted under Heeling Coil Procedure*).

(*e*) Difficulty may be experienced in obtaining sufficient correction if the Flinders bar is short, but may be achieved by the use of additional windings or coils.

(*f*) Be sure that final setting *would not permit* more than 1.4 amperes to flow through the variable control resistor, at *maximum* degaussing coil current. This is approximately equivalent to 1.5 volts per winding across B–M compass coil.

(*g*) Repeat (*c*, *d*, *e*, and *f*) for all other degaussing coils (F, Q, A) *individually*, while compass is still deflected to 090° to 270°. Correct each with B–F, B–Q, and B–A coil windings, respectively.

(*h*) Deflect compass card to 000° or 180° heading, whichever is closer, with all degaussing coils secured.

(*i*) Energize M degaussing coil to *maximum operating* current, and note the deviation of the compass.

(*j*) Adjust current in the C–M (sphere) compass coils until compass returns to original position.

(*k*) If correction is difficult, check:
  (1) Bucking sphere coil windings.
  (2) Need for more windings.

(*l*) Be sure that final setting *would not permit* more than 1.4 amperes to flow through the variable control resistor, at *maximum* degaussing coil current. This is approximately equivalent to 0.8 volt per winding across C–M (two winding) coils.

(*m*) Repeat (*i*), (*j*), (*k*), and (*l*) for all other degaussing coils (F, Q, A) *individually*, while compass is still deflected to 000° or 180°. Correct each with C–F, C–Q, and C–A coil windings, respectively.

(*n*) Now that the H, B, and C components are compensated for each degaussing coil, check that all coil connections and jumpers are *secured*. Then *repeat* the entire process for the refinement of each component because voltage drops, coil misalignments, and interaction of vector effects create possible discrepancies on the first approximation. (See art. 124.)

3. Type "G" compensating coil procedures. (*Type "K" coil procedure or intercardinally mounted type "T" coil procedure is the same, except for voltage limitations noted in art. 129. Heeling adjustments for any type coils are made as in Section B–1 of this Check-off list*):

(*a*) Replace the dip needle with regular compass.

(*b*) Deflect compass card to 135° or 315° heading, whichever is closer, with all degaussing coils secured (art. 125).

(*c*) Energize M degaussing coil to *maximum operating* current, and note deviation of the compass. (See note at end of art. 108.)

(*d*) Adjust current in the NW./SE.–M compass coil until compass returns to original position. If increasing the current in this coil creates a greater deviation, reverse the NW./SE.–M compass coil polarity. (*Coarse and fine adjustments are achieved as noted under Heeling Coil Procedure.*)

(*e*) Be sure that final setting *would not permit* more than 1.4 amperes to flow through the variable control resistor, at *maximum* degaussing coil current. This is approximately equivalent to 1.7 volts per winding across NW./SE.–M (three-winding) compass coil.

(*f*) Repeat (*c*), (*d*), and (*e*) for all other degaussing coils (F, Q, A) *individually*, while compass is still dedeflected to 135° or 315°. Correct each with NW./SE.–F, NW./SE.–Q, and NW./SE.–A coil windings, respectively.

(*g*) Deflect compass card to 045° or 225° heading, whichever is closer, with all degaussing coils secured.

(*h*) Energize M degaussing coil to *maximum operating* current, and note deviation of the compass.

(*i*) Adjust current in the NE./SW.–M compass coil until compass returns to original position.

(*j*) Limit coil current, as in (*e*) above.

(*k*) Repeat (*h*), (*i*), and (*j*) for all other degaussing coils (F, Q, A) *individually*, while compass is still deflected to 045° or 225°. Correct each with NE./SW.–F, NE./SW.–Q, and NE./SW.–A compass coil windings, respectively.

(*l*) Now that the H, NW./SE., and NE./SW. components are compensated for each degaussing coil, check that all coil connections and jumpers are *secured*. Then repeat the entire process for the refinement of each component because voltage drops, coil misalignments, and interaction of vector effects create possible discrepancies on the first approximation. (See art. 124.)

NOTE.—This dockside compensation is subject to errors from welding, passing cranes, swaying of ship, adjacent ships, and shore interferences. If a degaussing coil ever creates a deviation which is over 90°, or makes compensation difficult, energize the degaussing coil with reversed polarity and compensate as usual. Another good rule is to always compensate the largest component effect first.

109. C. Final compensation at sea.—(*Compensation and final deviation data are best made with the coils energized to their operating conditions for at least 20 minutes. If any coil requires securing by reversals, it should be so secured each time during the process of compensation.*)

1. Purpose.

(*a*) The final compensation is made at sea *after* the magnetic adjustment in order to improve any degaussing deviations still existing as a result of inaccuracies in the dockside compensation from:

(1) Dockside interferences.

(2) Movement of the soft iron correctors as a result of magnetic adjustment.

(3) Inaccuracies of dockside deflection methods

(4) Poor coil alignments.

(5) Poor directive force on the unadjusted compass at the time of dockside compensation.

2. Compensation.

(*a*) The different coil compensations are made *individually*, with *maximum operating currents*, and on the *same headings* as previously described under article 108. The differences in this case are (1) the ship is actually placed on the compass headings, rather than by deflection of the compass card to the desired headings, and (2) the degaussing coils are successively energized on one heading, compensating the deviation of each degaussing coil individually until all degaussing coils are on. All degaussing coils are then secured and the ship placed on a heading 90° from the previous heading and the procedure repeated.

3. Deviation curves.

(*a*) After refinements are made on each coil compensation, and everything is physically and electrically secured, a deviation curve is taken with the *degaussing coils at the proper current settings*, as indicated on the degaussing chart. This deviation curve is in addition to the normal undergaussed curve, covered in articles 89, 126, and 132, and should be recorded as such on the standard Navy Form NBS 1104 or 1105, as well as in the *Compass Record Book*. Conditions of coil current settings are all recorded on Navy Form CC–1.

(*b*) Should the deviations caused by degaussing be unsatisfactory, part or all of the foregoing procedure will have to be repeated until the errors are split between opposite headings.

110. The above *check-off list* describes a step-by-step procedure for compensation of the different degaussing effects. It will be noted that the compensation procedures for the general types of compass coil installations are presented; and, the adjuster will be governed in his selection of the appropriate procedure by the type of compass compensating coil installation on the ship.

Further details concerning the different type compass compensating coils, the general principles of degaussing compensation, schematic and installation wiring arrangements, principles of operation, etc., are to be found in chapter XI.

Frequent, careful observations should be made to determine the constancy of deviations due to degaussing, and the results systematically recorded. Significant changes in deviations due to degaussing will indicate the need for recompensation.

CHAPTER XI. DEGAUSSING COMPASS COMPENSATION

A. General Principles

111. Degaussing effects.—The degaussing of ships for protection against magnetic mines has created additional effects upon magnetic compasses which are somewhat different from the permanent and induced magnetic effects usually encountered. These effects may be considered as *electro-magnetic* effects which depend upon:

(1) Number and type degaussing coils installed.

(2) Magnetic strength and polarity of the degaussing coils.

(3) Relative location of the different degaussing coils with respect to the binnacle.

(4) Presence of masses of steel which would tend to concentrate or distort magnetic fields in the vicinity of the binnacle.

(5) The fact that degaussing coils are operated intermittently, with variable current values, and with different polarities as dictated by necessary degaussing conditions.

112. The magnetic fields at the binnacle must be considered separately for each degaussing coil. The magnetic field from any individual degaussing coil will vary proportionately with the excitation of the coil, and its direction will completely reverse with changes in the coil polarity.

Uncompensated degaussing coil effects create *deviations* of the compass card and *conditions of sluggishness and unsteadiness* which are similar to, and generally larger than, the effects of normal ship's magnetism on the magnetic compass.

113. Degaussing compensation.—The fundamental principle of *compass compensation* is to create magnetic fields at the compass which are at all times equal and opposite to the magnetic effects of the degaussing system. Creation of such magnetic fields is accomplished by appropriate arrangements of electrical coils about the binnacle. To do this completely, it is necessary to arrange coils about the binnacle for each *effective* degaussing circuit such that they create their opposing effect either directly or by a combination of component parts. In most cases it is best to create this compensating field by a combination of *three vectors* on axes arranged mutually 90° apart, rather than by one vector adjusted at the proper angle. This renders compensation completely electrical.

Figure 38 illustrates the conception of a *resultant degaussing magnetic field* across a compass as having three separate components, mutually 90° apart.

114. The various standard compass coil installations utilize a *three-coil arrangement*, of one type or another, to achieve compensation by the three-component method. Such a group of coils are so interconnected that they can be *individually adjusted;* and each group is so connected to its associated degaussing coil that its compensation effect will *automatically* change with changes in the degaussing coil effect.

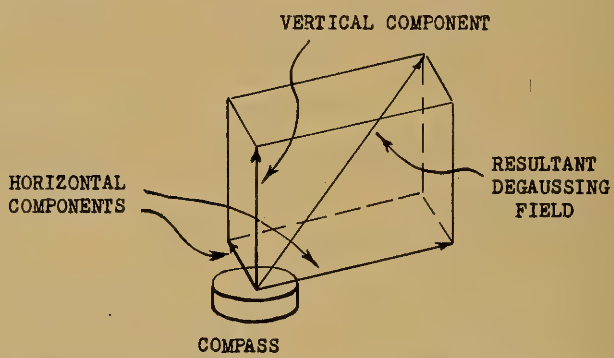


FIGURE 38.—Resultant degaussing field and its equivalent three vector components.

B. Compass Coil Installations

115. Cardinally arranged iron core coils.—Pictures of the type "B" and type "B Modified" compass compensating coils are presented in figures 39 and 40. It will be observed that these installations provide three components of coil correction, as discussed above. The *heeling* (*H*) *coil* about the binnacle creates its effect vertically across

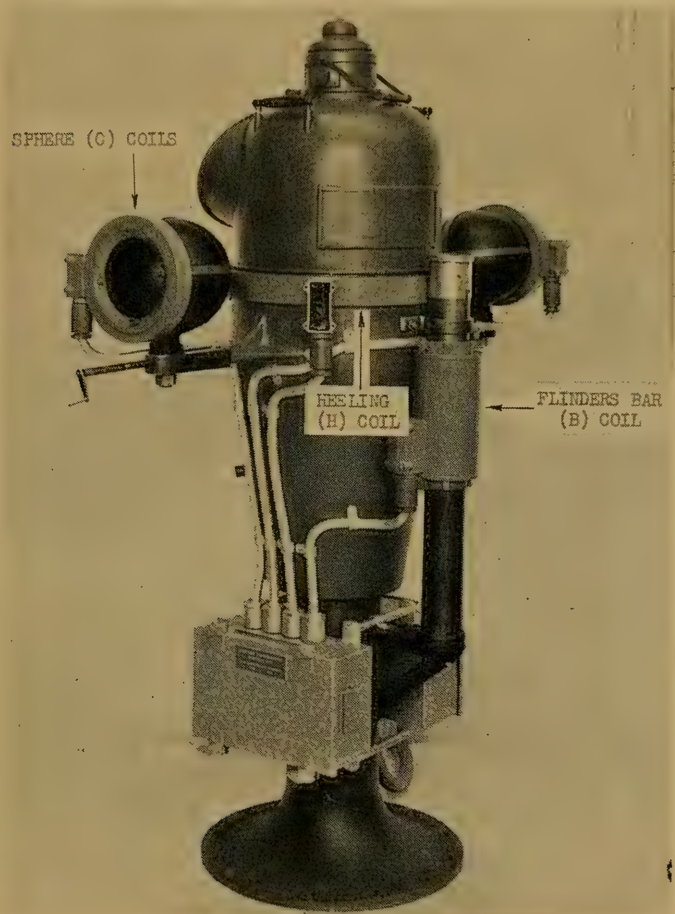


FIGURE 39.—Compass compensating coils (type "B") mounted on Navy standard No. 1 binnacle.

the compass so as to compensate the vertical component of the degaussing field. The *Flinders bar* (*B*) *coil* creates its effect fore-and-aft across the compass, and the *sphere* (*C*) *coils* create their effect athwartship across the compass, thus providing compensation for the two horizontal components of the degaussing field.

The (H), (B), and (C) coils are to be likened to the heeling magnet and the *B* and *C* semicircular magnets respectively, as in normal adjustment. Compensation is also achieved in a fashion similar to normal adjustment by adjusting the (B) coil currents when the ship is

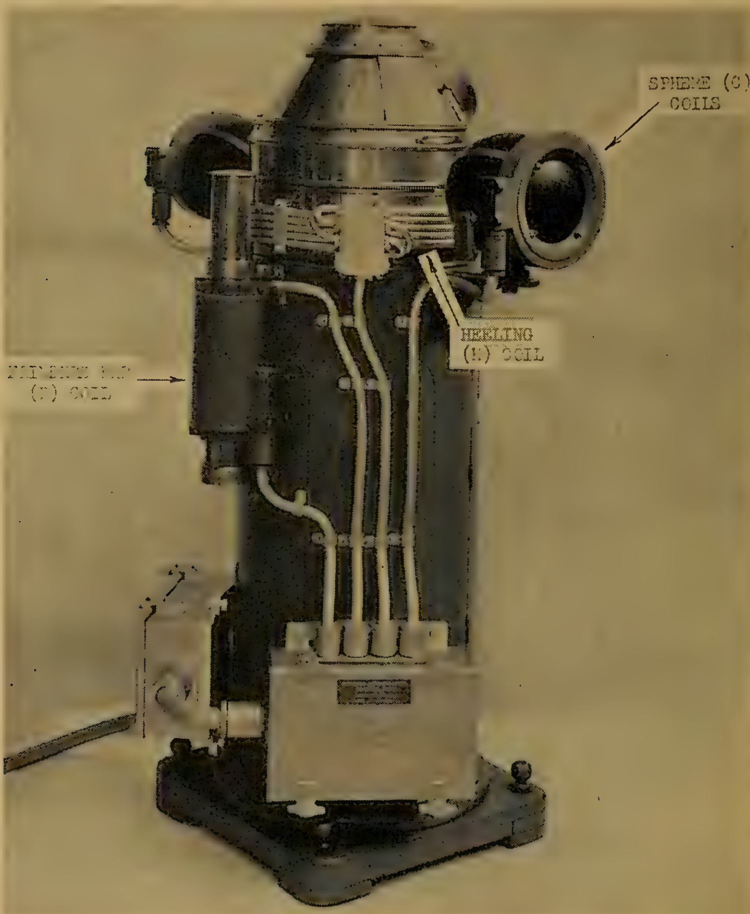


FIGURE 40.—Compass compensating coils (type "B" modified) mounted on merchant type binnacle.

on east or west headings and by adjusting the (C) coil currents when the ship is on north or south headings. *Several separate windings* are available in each coil so that they may be used to correct for similar component effects of different degaussing coils.

The utilization of such *iron core coil installations*, however, presents certain installation and compensation difficulties, as well as increasing the mutual relationship between the magnetic adjustment and the degaussing coil compensation.

116. Intercardinally arranged air core coils.—Pictures of the type "G" and type "K" compass compensating coils are presented in

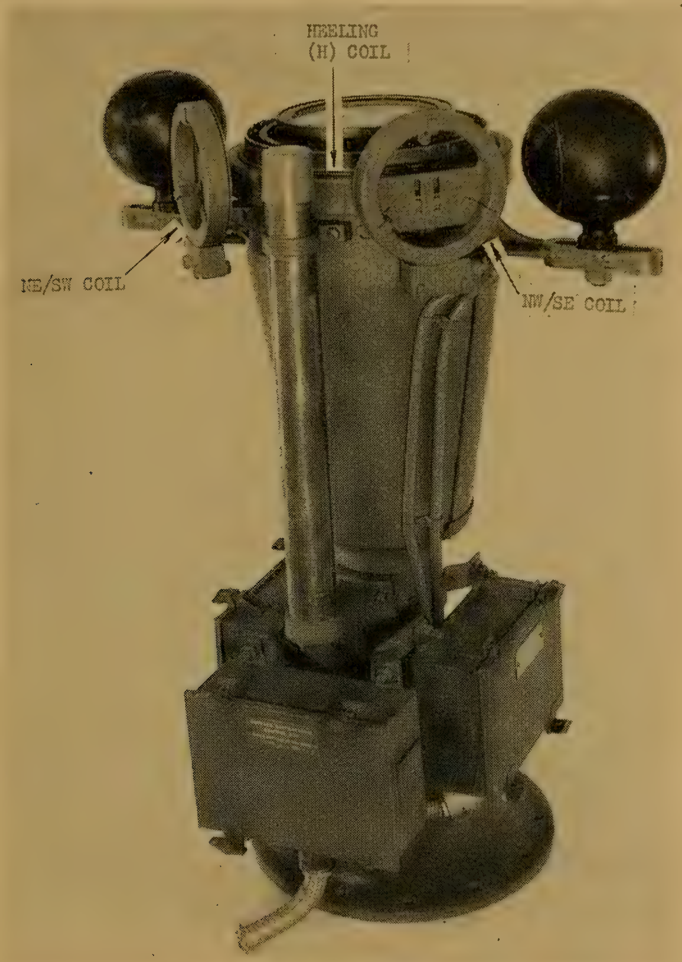


FIGURE 41.—Compass compensating coils (type "G") mounted on Navy standard No. 1 binnacle.

figures 41, 42, and 43. These installations are adaptable to a great variety of binnacle arrangements, and are less dependent upon sphere and Flinders bar conditions. These installations also provide three components of coil compensation, as discussed above. The *heeling* (*H*) *coil* about the binnacle creates its effect vertically so as to compensate for the vertical component of the degaussing field. The windings of the "G" and "K" coils which create horizontal compensating fields are arranged so as to produce these fields on the two intercardinal axes, rather than on the fore-and-aft and athwartship axes.

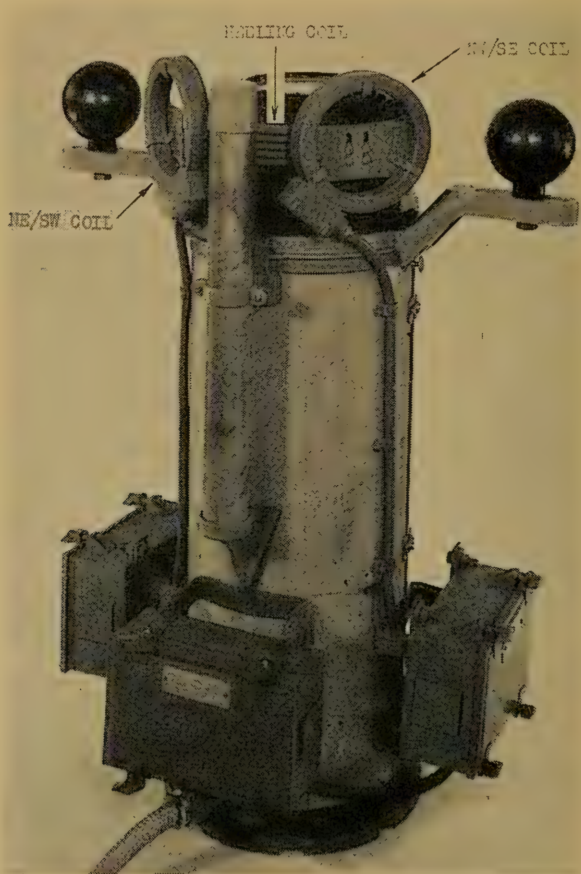


FIGURE 42.—Compass compensating coils (type "G" modified) mounted on shelf type binnacle and plywood pedestal.

The intercardinal coils on the NW./SE. axis are termed the *NW./SE. coils*, and the others are termed *NE./SW. coils*. The "G" coils should be carefully and rigidly mounted at the intercardinal positions with their axes perpendicular and on a level with the compass card. The "K" coils are constructed 90° apart, but the assembly must be mounted with the plane of the heeling coil approximately on a level with the compass card. The centerline of the intercardinal "K" coils will be approximately $2\frac{1}{2}$ inches below the level of the compass card. *Several separate windings* are available in each coil so that they may be used to correct for similar component effects of different degaussing coils.

The NW./SE. and NE./SW. coils are so termed not only because of their relative location on the binnacle, but because those are also

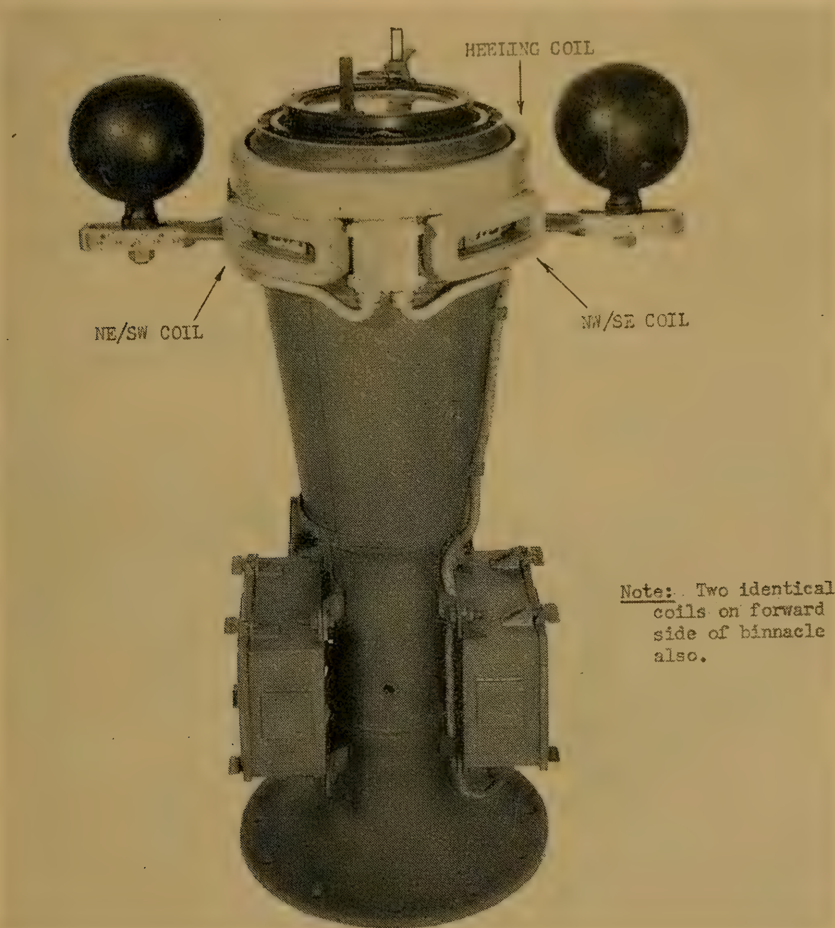


FIGURE 43.—Compass compensating coils (type "K") mounted on Navy standard No. 1 binnacle.

the ship's headings on which the coils are individually compensated.

These *air core coil installations* are designed to simplify installation and wiring, improve compensation, and reduce the mutual relationship between the magnetic adjustment and the degaussing coil compensation.

117. Type "T" cardinally or intercardinally arranged air core coils.—Figure 44 illustrates the type "T" compass compensating coils as used with the Magnesyn type remote reading magnetic compass. Type "T" coils may also be used with vehicle type compasses fitted to degaussed submarines and with boat or shelf-type compasses. The "T" coil is mounted intercardinally when the other compensating

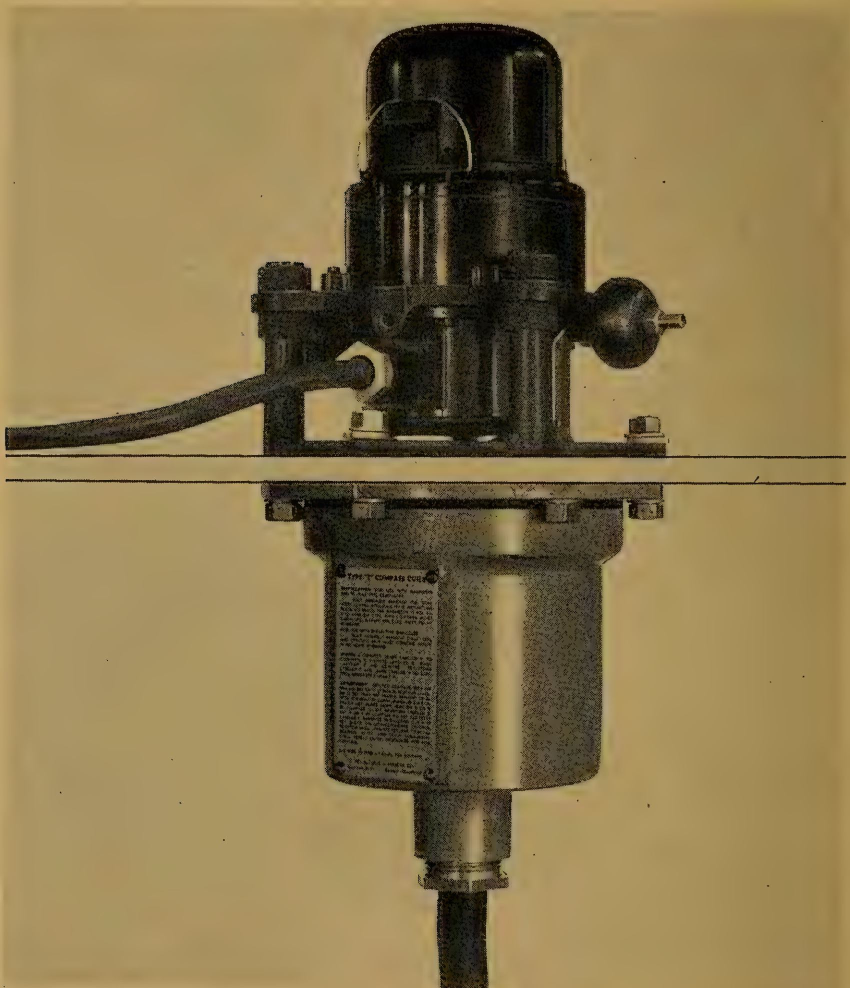


FIGURE 44.—Compass compensating coils (type "T") as used with Magnesyn transmitter and special mounting bracket.

coils on a particular vessel are intercardinally mounted (as on all new construction vessels), and it is mounted cardinally when the other compensating coils on a particular vessel are cardinally mounted. It is essential that the vertical axis of the "T" coil be rigidly aligned with the compass to be compensated.

C. Wiring

118. Schematic wiring.—The *elementary wiring diagram* for any three-circuit degaussing compensation coil installation is arranged as shown in figure 45, whether for types "B," "G," "K," or "T" coils.

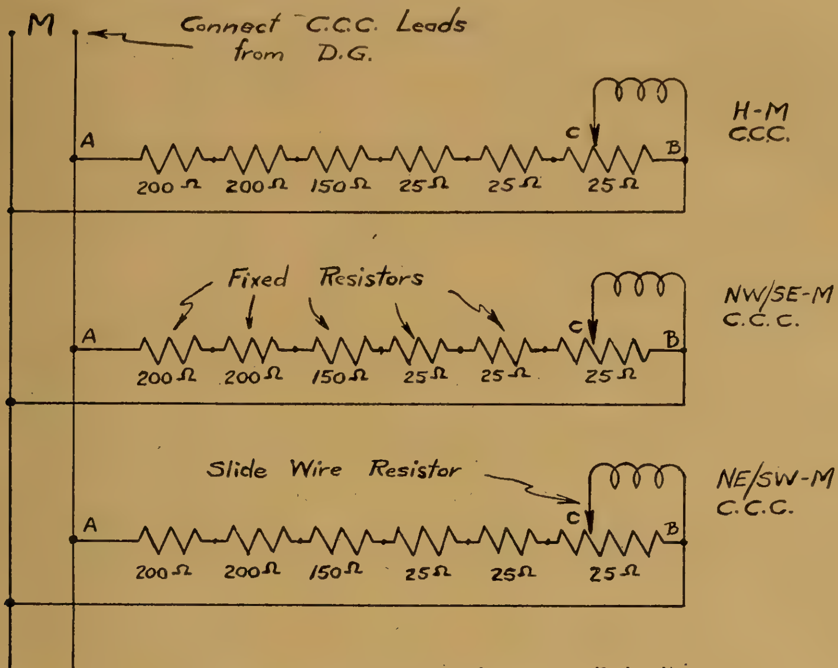


FIGURE 45.—Elementary wiring of compass coil circuit.

119. Control box wiring.—The *internal wiring* of the Type "A" compass compensating coil control box is illustrated in figure 46.

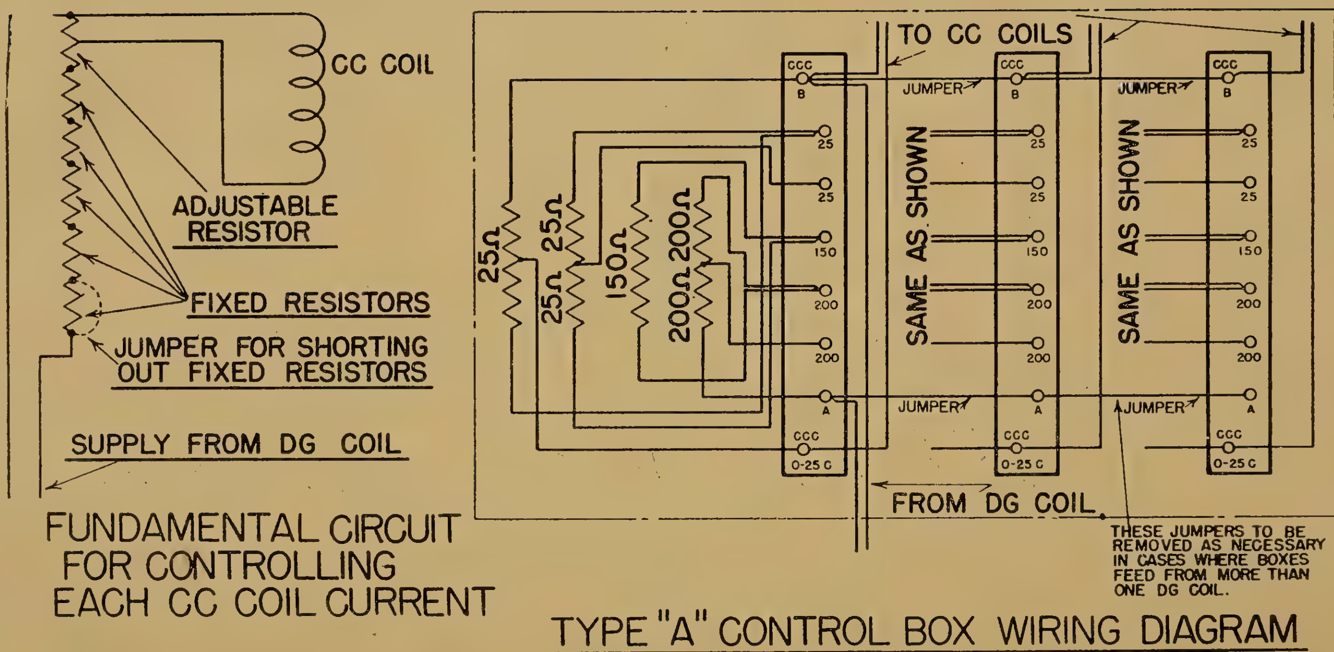
Adjustment of current to any compensating coil through this type "A" control box is as follows:

(1) First, set slide wire resistor in approximately midposition.

(2) Then, roughly obtain the desired current by shorting out sufficient series resistance in the appropriate circuit, by the use of resistor taps on the terminal strip. (It is always better to leave a *maximum amount of resistance in the circuit*, if possible.)

(3) Finally, the current adjustments may be refined by further manipulation of the slide wire resistor.

120. Interconnection wiring.—A typical *interconnection wiring arrangement* for a type "B" compass coil installation is illustrated in figure 47. A typical *interconnection wiring arrangement* for a type "G" compass coil installation is illustrated in figure 48. A typical *interconnection wiring arrangement* for a type "K" compass coil installation is illustrated in figure 49. A typical *interconnection wiring*



TOTAL RESISTANCE OF BANK MAY BE VARIED BY FOLLOWING MEANS:
(1) SLIDER ON ADJUSTABLE RESISTOR
(2) SHORT OUT FIXED RESISTORS AT TERMINAL STRIP
(3) CONNECT RESISTORS IN PARALLEL

FIGURE 46.

arrangement for a type "T" compass coil installation is illustrated in figure 50.

121. Connection of compass coil to degaussing.—The connections of compass compensating coil systems to their corresponding degaussing coils differ for electrically different degaussing circuits. The primary prerequisites for this *voltage supply* are:

(1) It should reverse in polarity as the degaussing coil reverses polarity.

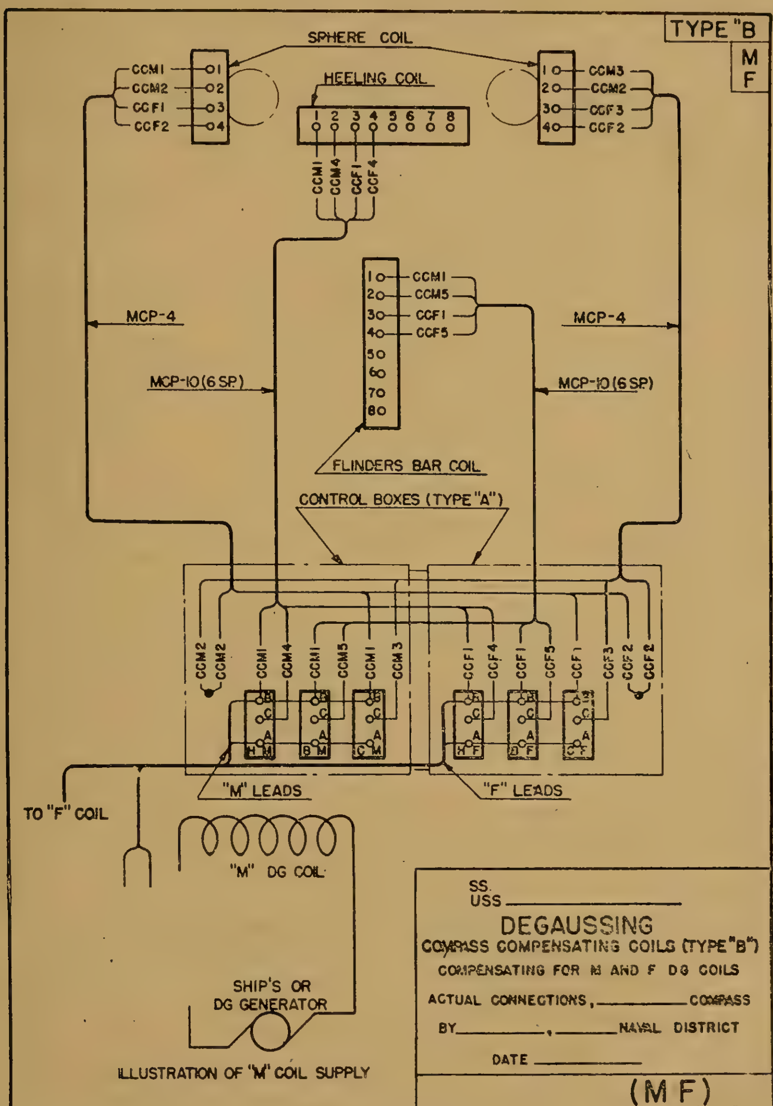


FIGURE 17.

(2) It should be proportional to the magnetic effects of the degaussing coil.

(3) It should be preferably from 6 to 10 volts.

(4) It must be such that fault conditions or fuse failures on any one of parallel degaussing coil circuits will not destroy its proportionality to the magnetic effects of the degaussing coil.

Figure 51 illustrates such *voltage connections* to different type degaussing installations.

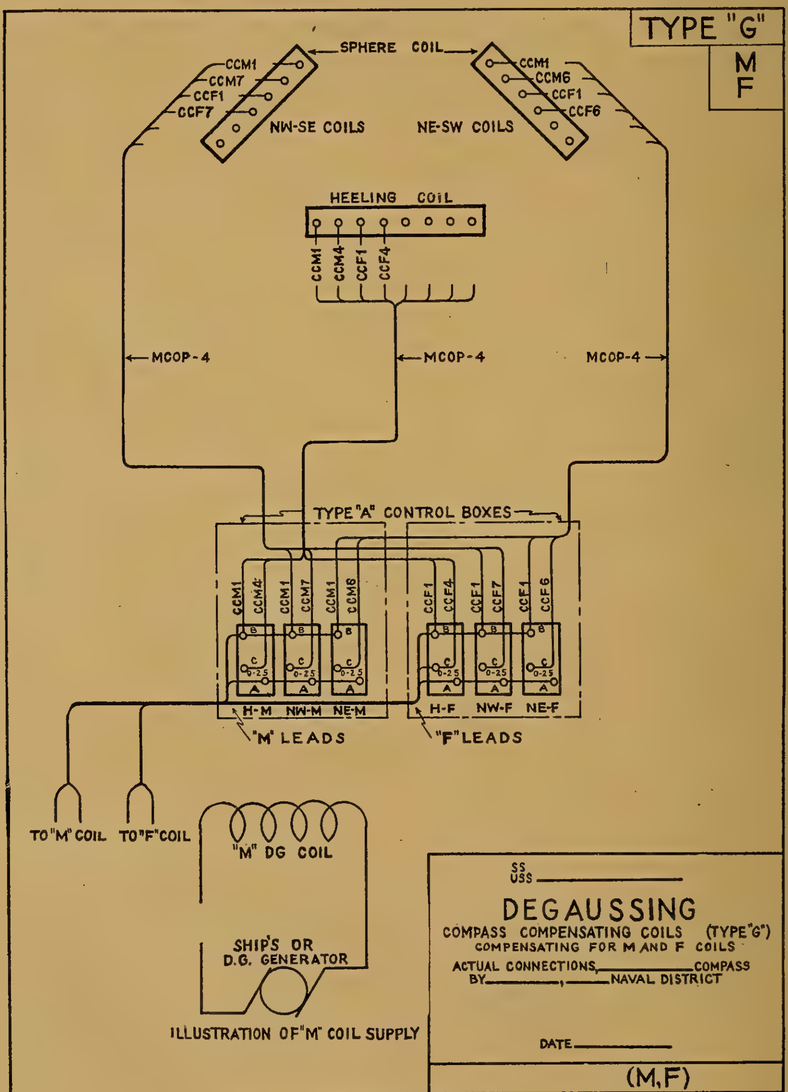
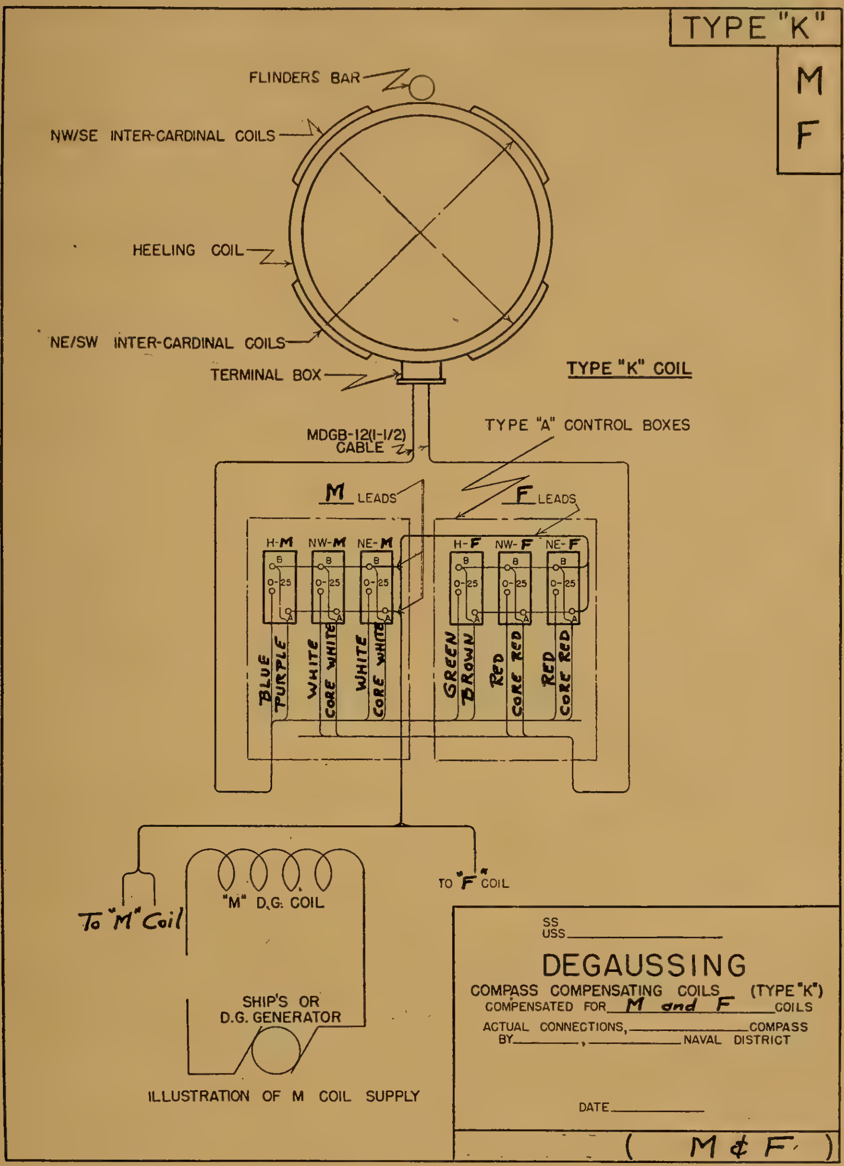


FIGURE 48.



TYPE "K"
M
F
FLINDERS BAR
NW/SE INTER-CARDINAL COILS
HEELING COIL
NE/SW INTER-CARDINAL COILS
TERMINAL BOX
TYPE "K" COIL
TYPE "A" CONTROL BOXES
MDGB-12(1-1/2) CABLE
M LEADS
F LEADS
H-M
NW-M
NE-M
H-F
NW-F
NE-F
BLUE
PURPLE
WHITE
CORE WHITE
WHITE
CORE WHITE
GREEN
BROWN
RED
CORE RED
RED
CORE RED
To "M" Coil
"M" D.G. COIL
TO "F" COIL
SHIP'S OR D.G. GENERATOR
ILLUSTRATION OF M COIL SUPPLY
SS
USS
DEGAUSSING
COMPASS COMPENSATING COILS (TYPE "K")
COMPENSATED FOR M and F COILS
ACTUAL CONNECTIONS, COMPASS
BY , NAVAL DISTRICT
DATE
(M & F)

FIGURE 49.

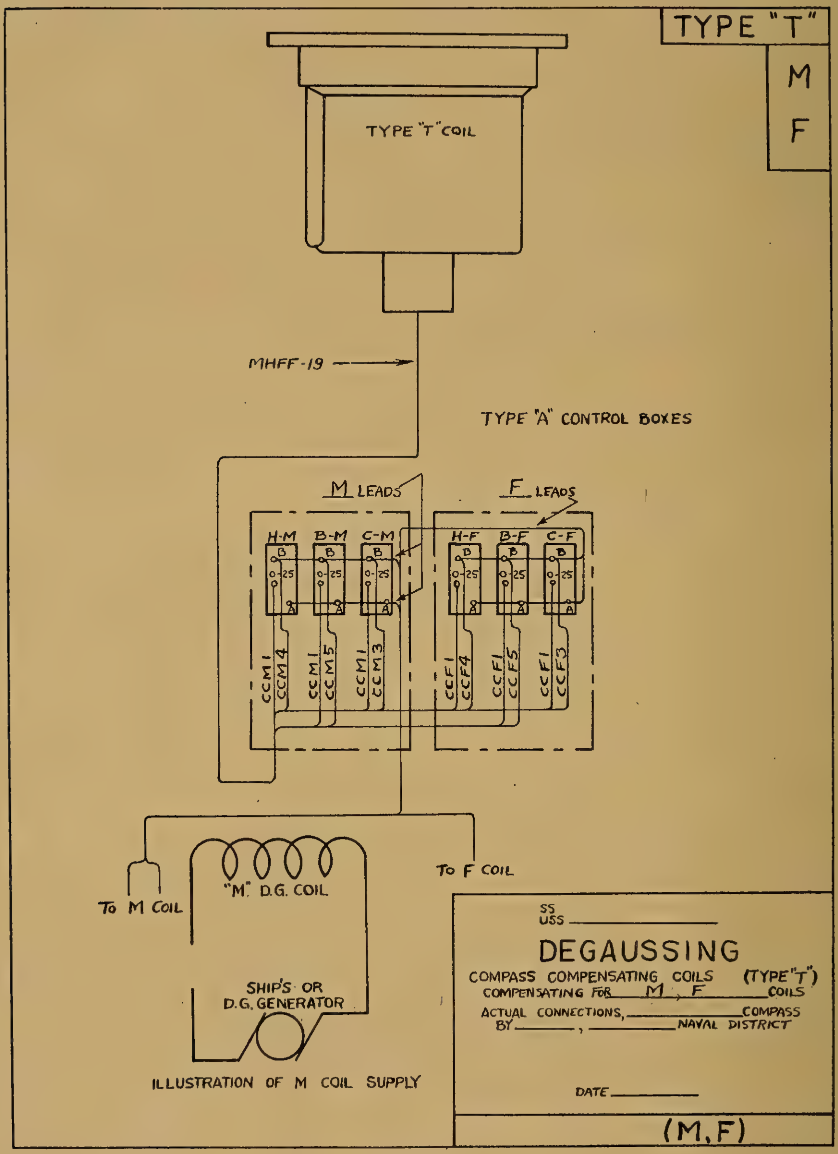

TYPE "T"
M
F
TYPE "T" COIL
MHFF-19
TYPE "A" CONTROL BOXES
M LEADS
F LEADS
H-M
B-M
C-M
H-F
B-F
C-F
CCM1
CCM4
CCM1
CCM5
CCM1
CCM3
CCF1
CCF4
CCF1
CCF5
CCF1
CCF3
To M COIL
"M" D.G. COIL
To F COIL
SHIP'S OR
D.G. GENERATOR
ILLUSTRATION OF M COIL SUPPLY
SS
USS
DEGAUSSING
COMPASS COMPENSATING COILS (TYPE "T")
COMPENSATING FOR M , F COILS
ACTUAL CONNECTIONS, COMPASS
BY , NAVAL DISTRICT
DATE
(M, F)

FIGURE 50.

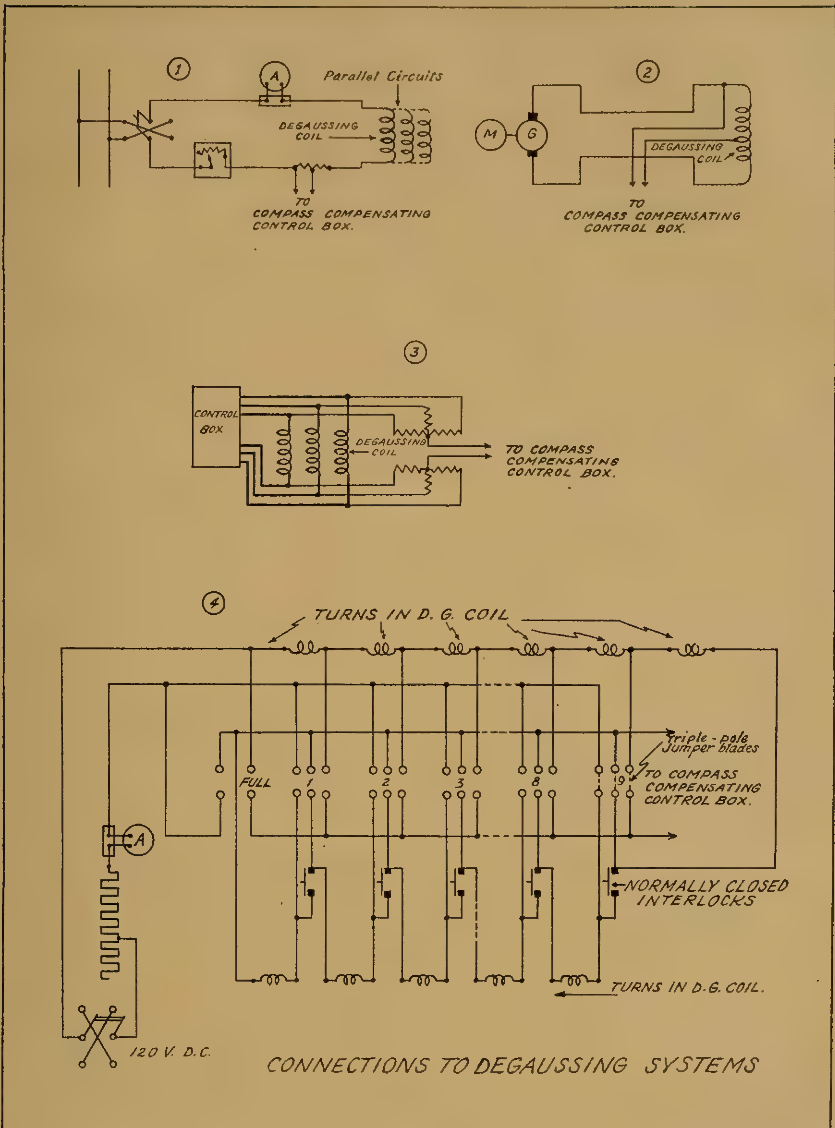


FIGURE 51.

D. Compensation

122. Principles of compensation.—Degaussing compass coil *compensation* consists of regulating the current delivered to the coils so that no change in the magnetic field occurs at the center of the binnacle when the degaussing coils are energized, or the degaussing currents are varied. This regulation is accomplished in the control box by means of control resistors for each circuit. *When these resistors have once been set, their settings need not be altered with current changes in the degaussing circuits.*

Each compensating coil is controlled by a separate unit in the control box. Wiring diagrams in figures 47 to 50 show this in detail. Each circuit should be properly labeled.

It is best to check coil installations electrically and compensate at *dockside* before the ship leaves the yard. Although accuracy of compensation is impaired by welding, adjacent ships, and moving cranes, time and trouble are still saved for the ship during final compensation at sea. All this results from the fact that trouble-shooting is the greater part of coil compensation. Chapter X presents details of compensation procedure.

Final compensation should be made at sea *after magnetic adjustment.* This will correct for the changes of Flinders bar length or movement of spheres, which might have been made as part of the magnetic adjustment, as well as refine the approximate dockside settings of the compass coils under more ideal conditions.

123. Whether compensation is made at dockside or at sea, the principle is merely one of *isolating* the three vector effects such that each vector coil can be adjusted *separately.* The two 90° horizontal components are isolated by obtaining proper compass headings relative to the ship's axes. At sea these headings are usually obtained by swinging ship; while at dockside, they may be simulated by deflection of the compass with permanent magnets.

It is good practice to compensate for the *heeling effects first*, because the heeling coil currents create additional induction effects in the Flinders bar, which in turn creates *B* deviations on the compass. The details of the heeling coil compensations are given in chapter X.

It is pointed out here that horizontal component fields create maximum deviations when the fields are perpendicular (striking broadside) to the compass needle; and, compensation is achieved by energizing coils which create similar fields in opposite directions. Reference is made to figure 52 for an illustration of this principle.

In figure 52 the ship is on a NE. heading and, with the degaussing coils deenergized, the needles (or N.–S. line) of the compass card are on an axis 45° to the left of the ship's fore-and-aft line (on the NW./SE. axis). If any degaussing coil is energized, say the M coil, deviation will be caused by a component of the degaussing coil field which is perpendicular to the NW./SE. axis, or in line with the

NE./SW. axis. A compensating component may therefore be created by energizing the NE./SW.–M coil until the compass indicates the original heading. *This simply means that the current in the NE./SW.–M coil is adjusted to compensate for any deviation caused by the M degaussing coil on a NE. or SW. heading.* Conversely, with the ship on a NW. or SE. heading any deviation due to the M degaussing coil is corrected by use of the NW./SE.–M coil. The full details of all such compass coil compensation are presented in chapter X. These principles of component compensation apply whether the component axes are intercardinally or cardinally arranged.

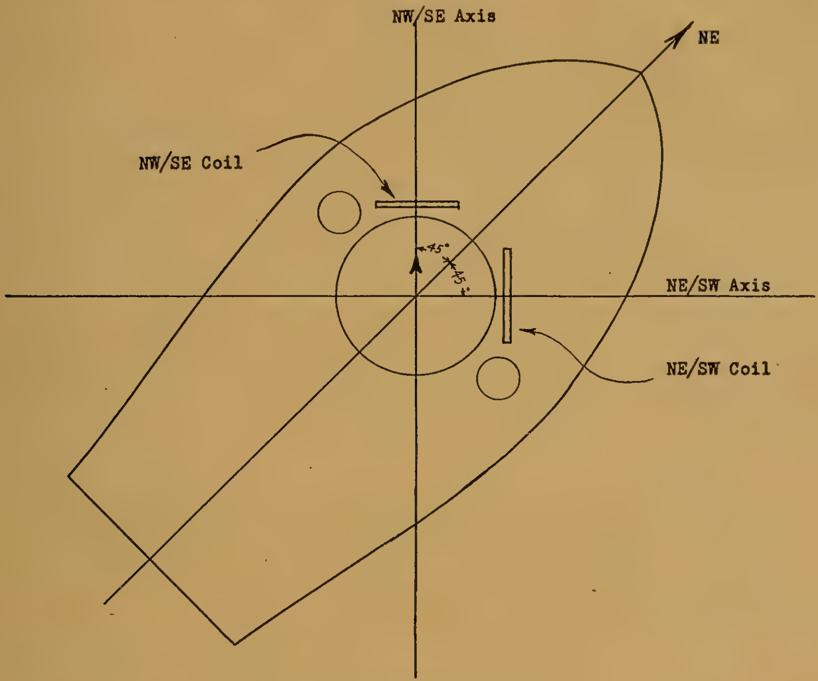


FIGURE 52.—Intercardinal axes.

124. If the deviation from degaussing is greater than 90°, or compensation with any degaussing coil energized is difficult, that degaussing coil should be energized with *reversed polarity* in order to facilitate adjustment. Compensation is similarly simplified by always compensating the *larger* of the two horizontal components first.

After both horizontal components of coil compensation have been adjusted for each effective degaussing coil, it is advisable to check deviations on a compass heading somewhere between those used for compensation. There are several possibilities of error which may be caught at this time, for example:

(1) Outside interferences may have been compensated by error.

(2) In correcting the second vector, the additional electrical load may create sufficient voltage drop in the leads to change the previous adjustment.

(3) Coil misalignments may create slightly inaccurate compensation.

(4) Poor spacing of compass needles permits sextantal deviation errors, due to non-uniform magnetic fields.

The first three of these errors are easily corrected by repeating the entire sequence of coil compensation—a sort of successive approximation procedure. The fourth error is quite rare and is generally best corrected by replacing the faulty compass. Replacing the coil installation with a type "K" set of coils or a special arrangement of larger coils will also improve the nonuniform field trouble.

It is also necessary to try each degaussing coil at reversed polarity, individually and collectively, to be sure of reversibility, proportionality, and independence of each degaussing circuit and its compensation. Check to see that the coils are not overloaded at this time. Refer to chapter X or XII.

125. Should it be desired to *deflect* the compass to relative headings

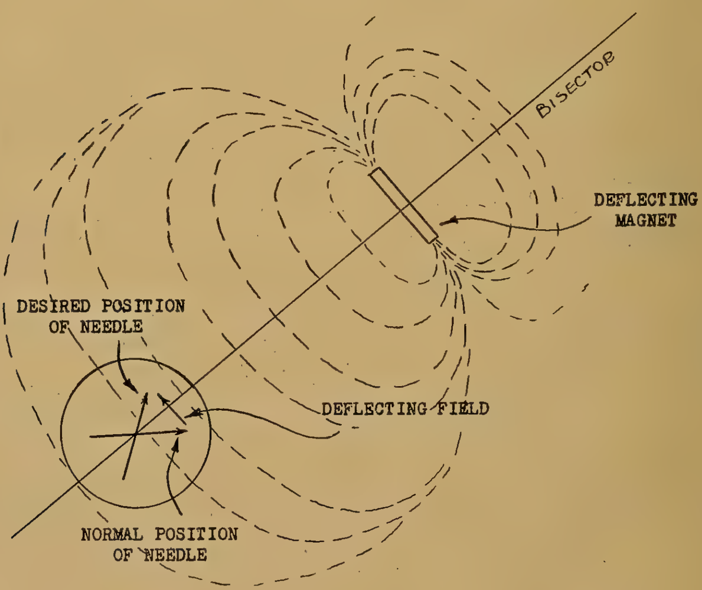


FIGURE 53.—Deflection of compass by magnets.

rather than swing ship, it can be done by carefully placing magnets so as to create a deflecting field perpendicular to the bisector of the angle between the original and desired position of the compass needle, as illustrated in figure 53. For this procedure, the use of stronger magnets at a greater distance from the compass makes for a more symmetrical deflecting field and more accurate compensation. Applying fields in this manner will simulate heading conditions quite accurately, since the directive force on the needle is not disturbed.

E. Operation

126. Deviation curves.—Because of the many difficulties of compensations it is not always possible to eliminate completely degaussing effects on the compass; but, compensation should generally be such that deviations due to degaussing alone are below 2° on all headings. For the same reasons that a deviation curve is recorded for *undegaussed conditions* of the ship after magnetic adjustment (art. 89), a deviation curve should likewise be recorded for *degaussed conditions* after the final coil compensation. These two curves will then be available for appropriate use under either condition of navigation. These two deviation curves are recorded on standard Navy Forms NBS 1104 or 1105 as illustrated in Figure 54, and in the *Compass Record Book*, NBS 1101. Article 132 discusses the purposes of the various NBS Record Forms more fully. Details of coil current settings and uncompensated deviations are recorded on the Navy Form CC–1, illustrated in figure 55.

The error due to degaussing is the *difference* between the deviations observed with degaussing on and degaussing secured, and is not the total deviation of the degaussed condition curve. Therefore the degaussed condition curve will be reliable only as long as the undegaussed condition curve is reliable even though the coils compensate perfectly all of the degaussing effects.

127. It is advisable to maintain a check on the deviation curves and to recompensate, if necessary, for the following reasons:

(1) Magnetic cargo, incorrect Flinders bar adjustment, deperming, etc., may tend to change the basic magnetic adjustment and thus change both deviation curves.

(2) Compensating coils are electrical circuits and subject to electrical troubles.

(3) Changes of Flinders bar length or sphere positions can change the degaussing effects or certain coil compensation effects on the compass.

(4) Structural changes, magnetic cargo, or degaussing coil changes can change the degaussing effects at the compass.

128. Occasionally it will be noticed that the compass deviates considerably when the degaussing coils are changed *rapidly*. It should, if correctly compensated, settle back to the proper reading after a few seconds. This condition is due to the difference in the rate of saturation of the degaussing coil and the compensating coil, and should not be alarming since in actual usage degaussing is never changed rapidly.

NAVSHIPS (250)
NBS 1104
Rev. (11-43)

MAGNETIC COMPASS TABLE

U. S. S. FLASH No. AP 999
BB. PC. ETC.

ST'D ☒ STEERING ☐ OTHER

Binnacle Type: Navy St'd /~~wood~~/~~other~~ MK. VII

Compass 7½ " Make Ritchie No. 3520

Type CC Coils "G" Date 1 Jan. 1944

SHIPS HD. BY COMPASS	DEVIATIONS		SHIPS HD. BY COMPASS	DEVIATIONS	
	DG OFF	DG ON		DG OFF	DG ON
0	1.0°W	1.0°W	**180**	1.0°E	1.0°E
15			195		
30			210		
45	0.5°W	0.5°W	**225**	0.5°E	0.5°E
60			240		
75			255		
90	0.0°	0.5°E	**270**	0.0°	0.5°W
105			285		
120			300		
135	0.5°E	1.0°E	**315**	0.5°W	1.0°W
150			330		
165			345		

~~CYCLE/DO NOT~~ CYCLE DG COILS WHEN SECURING

4 Alnico RED ~~FORE~~/AFT AT AVERAGE DISTANCE 13.1" FROM CARD

2 Alnico RED PORT/~~STBD~~ AT AVERAGE DISTANCE 15.7" FROM CARD

2 - 7" SPHERES AT 13.5" λ= 0.82 ~~ROUGH~~/GOOD/~~EXACT~~

HEELING MAGNET RED/~~BLUE~~ UP 15.5" FROM COMPASS CARD

12" OF BAR FORWARD/~~AFT~~ H= 0.190 Z= +0.530

Note: 3" gun forward of compass must be trained fore-and-aft.

SIGNED ADJUSTOR.

SUBMITTED *Lt. John Doe* NAVIGATOR.

APPROVED *Comdr. B. A. Mann* COMMANDING.

16--37250-1

(FRONT)

INSTRUCTIONS

1. This form shall be filled out by the adjustor (if available) or the navigator, one for each magnetic compass, as follows:
   a. After each normal adjustment of the magnetic compasses.
   b. After each degaussing compass compensation coil adjustment.
   c. Each time the vessel crosses the magnetic equator.
   d. As of 30 June each year if it has not already been submitted, as above, during the previous 12 months.

2. When the "DG ON" curve is taken, the degaussing coils must be set to the proper value for latitude and heading as specified in DGP 40 series in the Degaussing Folder.
(Charts dated 10 Dec., 1943)

3. Each time the form is filled out, a copy is to be sent to BuShips.

4. The adjustor should determine whether the MFQ coils should be cycled when securing and so indicate on the form.

5. The first time this report is filled out for a given compass, the following performance data should be included:
   a. Compass steady/~~unsteady~~ at sea.
   b. ~~Compass slow/sluggish/sticky.~~
   c. Deviations ~~change~~/remain reliable.
   d. Sweeping operations do/do not create unreliable deviations.
   e. Degaussed deviations ~~do~~/do not vary.
   f. Overhauls, gunfire, flashing, wiping, deperming, with dates and effect on magnetic compass.

6. On subsequent submissions of this report enter only performance data (par. 5) which has changed from that reported on the previous report, or which is seriously affecting the magnetic compass.

7. This report supersedes NBS 1102, 1104, 1106, 1107, and CC-2.

RECORD BELOW DATA FROM BOTH SIDES OF PREVIOUS NBS 1104 ALSO DEVIATIONS BEFORE THIS READJUSTMENT

DATE	H	Z	DEV. BY COMPASS		BAR (FORE / AFT)	BY Z LOOP	CALCULATED	ROUGH	OTHER
			090	270					
7/5/43	.32	.00	0°	0°	☐ 0" ☐			X	
1/1/44	.19	+.53	9.0°E	9.0°W	☐ 0" ☐				obs.
1/1/44	.19	+.53	0°	0°	☒ 12" ☐		X		
					☐ " ☐				
					☐ " ☐				
					☐ " ☐				
					☐ " ☐				

U. S. GOVERNMENT PRINTING OFFICE 16—37250-1

(BACK)

FIGURE 54.—Deviation table—Form NBS 1104.

Under certain conditions of *deperming*, *flashing*, or *wiping* it may be necessary to remove the Flinders bar, spheres, compass, and other compass equipment from the ship in order to avoid their becoming adversely affected by the strong magnetic fields which are employed in the process. Under some conditions the removal of equipment is not necessary. In case of doubt as to this procedure, it is better to remove the equipment.

If the degaussing coils are *secured improperly*, it may be observed that the compass does not settle back to the same undegaussed reading. This is due to the fact that the subpermanent magnetism of

NAVSHIPS(660g) FORM NO. CC-1
Rev. 1 May, 1944
(To be stapled to ship's CC Instruction Manual)

NAVY DEPARTMENT BUREAU OF SHIPS

COMPASS COMPENSATING COIL DATA

U.S.S. FLASH NO. AP 999 LOCATION N.O.B., Norfolk, Va. (City) DATE Jan. 1, 1944

1. COMPASS MAKER Ritchie, SERIAL NO. 3520, DESIGNATION Standard

BINNACLE MAKER Ritchie, MARK VII, POSITION Fly.Br. FLINDERS BAR LOCATION Fore LENGTH 12"

2. DEGAUSSING COILS M, F, Q, & A, CONTROL Field Rheostat of Degaussing Generator

3. C.C. COILS TYPE "G", SERIAL NO. –, VOLTAGE SUPPLY D.G. Generator (Full Voltage)

INSTALLED BY: N.N.S.& DD Co. DATE 9/18/43, MANUFACTURED BY Anaconda

TYPE "A" CONTROL BOXES 3 (Quantity) MOUNTED ON BINNACLE/BULKHEAD Bulkhead (Location)

4. OBSERVED DEGAUSSING EFFECTS BEFORE COMPENSATION

"NW/SE" EFFECT — COMPASS HEAD NW OR SE						"NE/SW" EFFECT — COMPASS HEAD NE OR SW						"H" EFFECT					
D.G. COIL	D.G. CURRENT + OR −	*AMP	COMPASS READING INITIAL	DEFLECTED	DEV	D.G. COIL	D.G. CURRENT + OR −	*AMP	COMPASS READING INITIAL	DEFLECTED	DEV.	D.G. COIL	D.G. CURRENT + OR −	*AMP.	HEELING EFFECT INITIAL	FINAL	EFFECT
M	+	80	135	129	6°	M	+	80	225	237	12°	M	+	80			Medium
F	+	75	135	189	54°	F	+	75	225	242	17°	F	+	75			Great
A	+	55	135	117	18°	A	+	55	225	214	11°	A	+	55			None

* DG current in 4 and 5 should be maximum setting for any zone as specified in DGP 40 series of Degaussing folder.

5 COMPENSATION OF COMPASS COILS

DOCKSIDE [X]

FINAL [ ]

COMPONENT	VOLTAGE ACROSS C. C.	VOLTAGE ACROSS SUPPLY LEADS	CURRENT IN C. C.	FIXED RESISTORS IN THE CIRCUIT
H – M	0.4	15	0.25	550 ohms jumped out
NW/SE – M	0.1		0.10	450 ohms jumped out
NE/SW – M	0.1		0.10	425 ohms jumped out
H – F	0.5	17	0.30	575 ohms jumped out
NW/SE – F	0.2		0.20	450 ohms jumped out
NE/SW – F	0.1		0.10	550 ohms jumped out
H – A	0.0	25	0.0	None
NW/SE – A	0.05		0.05	None
NE/SW – A	0.05		0.05	None

6 REMARKS:** None

7. SIGNED: Lt. John Smith, USNR (Adjuster) N.O.B., Norfolk, Virginia (Navy Yard or District)

** Include under remarks, details of any special equipment such as Type "A" Heeling and special difficulties such as hysteresis.

A38985

FIGURE 55.—BuShips Form No. CC–1.

the ship's hull has been temporarily changed by the excitation of degaussing. Such a *residual magnetism* can generally be eliminated by securing each of the degaussing coils by a *reversal and damping* process as follows:

TO SECURE COILS

(1) Start with maximum DG current used since the DG coil was last secured. Reduce the current to zero and energize to same value in the reverse direction.

(2) Reduce the current to zero and energize to three-fourths value in original direction.

(3) Reduce the current to zero and energize to one-half value in reverse direction.

(4) Reduce the current to zero and energize to one-fourth value in original direction.

(5) Reduce the current to zero and then energize to one-eighth value in reverse direction.

(6) Reduce the current to zero and open switch.

To eliminate possible residual, this procedure should be employed every time a degaussing coil is secured, if necessary. This procedure may not always be possible, as with some switch-type installations.

CHAPTER XII. COMPASS COMPENSATING COIL AND CONTROL BOX DATA

129. The *resistances* of different compass compensating coils are tabulated below. A knowledge of these resistances is extremely helpful in:

(1) Identifying coil circuits.
(2) Tracing wiring troubles.
(3) Calculating current values.
(4) Associating coil voltages with compass deviations.

On the basis of these resistance values, and the maximum permissible potentiometer current of 1.4 amperes, the table below is expanded to cover the *maximum permissible voltages* which can be placed across different corrector coil windings. Type "T" coils are limited to 1.0 amperes. With a knowledge of these limits, a quick check can be made while compensating, or a final check can be made on a complete compensation to insure against overload conditions.

Coil data

Coil	Number windings	Mean resistance at 80° F. (ohms. per winding)	Maximum allowable voltage per winding at 80° F.
Type "B":			
H	4	1.6	2.2
B	4	1.1	1.5
C	3	1.2	1.7
C	2	.6	.8
Type "G":			
H	4	1.6	2.2
NW./SE	3	1.2	1.7
NW./SE	2	.6	.8
NE./SW	3	1.2	1.7
NE./SW	2	.6	.8
Type "K":			
H	4	1.6	2.2
NW./SE	4	No. 1 wdg 5.2 Others 2.3	No. 1 wdg. 7.3 Others 3.2
NE./SW	4	No. 1 wdg 5.2 Others 2.3	No. 1 wdg. 7.3 Others 3.2
Type "T":			
H	3	4.8	4.8
B (NW./SE)	3	2.9	2.9
C (NE./SW)	3	2.9	2.9

130. The wiring arrangements of the type "A" control box are illustrated in figure 46. Taps are arranged on the terminal strip to simplify the connection and jumper procedure necessary for controlling coil currents. The fixed resistor combinations which are in series with the variable resistor may be connected in series or parallel, as desired, in order to obtain more delicate current control. The *maxi-*

mum current in the various resistors should not exceed the following values:

	Amperes
25-ohm variable resistor	1.41
50-ohm fixed resistor	1.00
150-ohm fixed resistor	.58
400-ohm fixed resistor	.35

CHAPTER XIII. COMPASS COMPENSATING COIL EFFECTS

131. Figures 56 to 60 are presented as useful information to compass coil compensators. The curves indicate the amount of correction which can be expected from different types of compass coils, under various conditions of load and iron core mounting. Familiarity with these curves will enable the compensator to:

(1) Anticipate the ability of certain coils to provide the necessary correction.

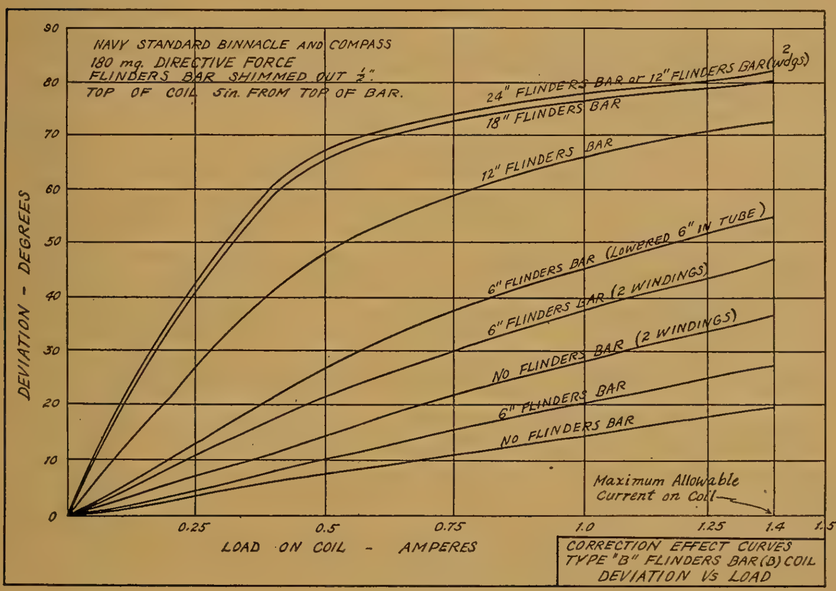


FIGURE 56.

(2) Anticipate changes in coil correction resulting from changing Flinders bar length or sphere positions.

(3) Detect wiring difficulties more readily by knowing the approximate voltage necessary for certain corrections.

(4) Appreciate sensitivity of coil adjustments when working on steep-sloped curves.

(5) Shift coils when necessary to correct many effects with a minimum installation.

(6) Load coil windings sensibly so as to avoid over-heating.

(7) Connect two or more windings in series if one winding is inadequate.

Compensation may be set up approximately by the use of these curves, but it is to be remembered that thermal resistance changes in the compensating coils, and the fact that different compass needle arrays are affected differently by similar coils, limit the accuracy of this method.

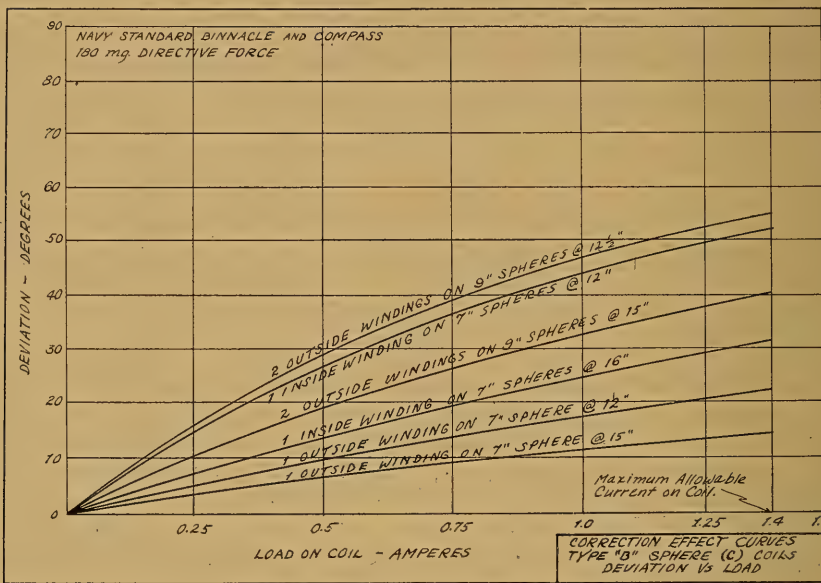


FIGURE 57.

These curves are taken on a Navy Standard compass with Navy Standard binnacle equipment. Different binnacle dimensions which alter coil spacings and different compass needle arrays will alter the data somewhat. The deviations are as observed for a specified directive force, but conversion can be made to any desired directive force inasmuch as the strength of a coil effect is *proportional to the tangent of the angle of deviation.*

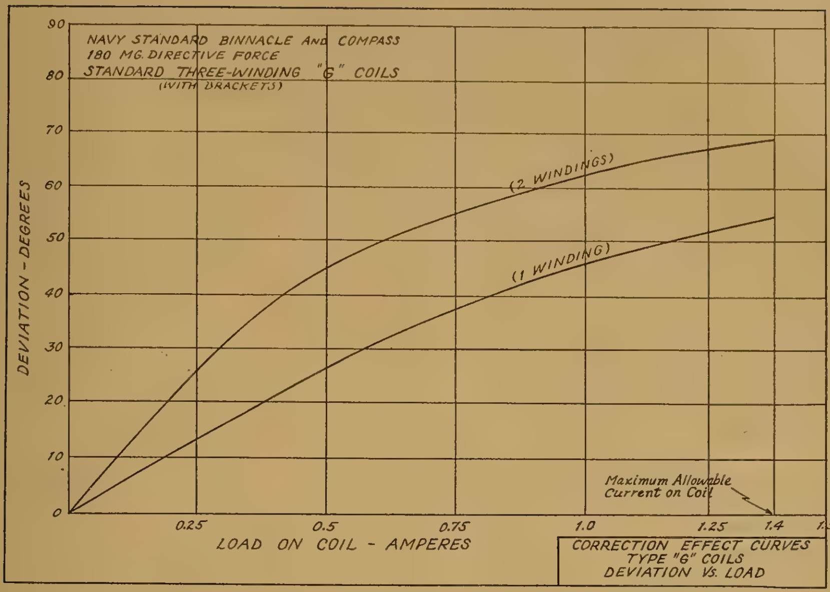


FIGURE 58.

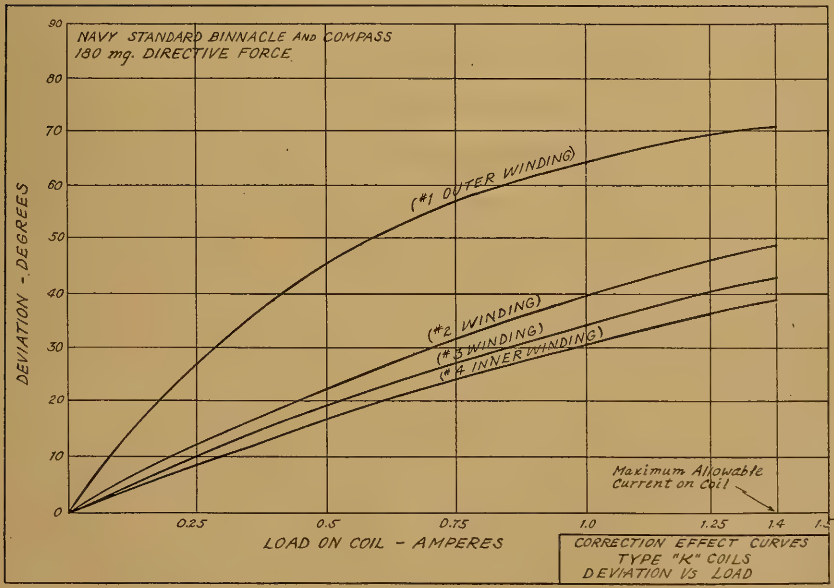


FIGURE 59.

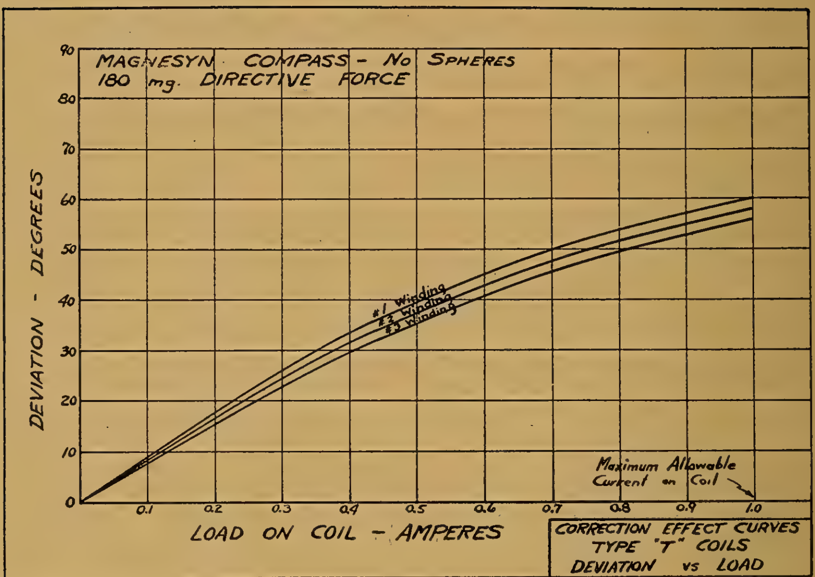

MAGNESYN COMPASS - No SPHERES
180 mg. DIRECTIVE FORCE
DEVIATION - DEGREES
90
80
70
60
50
40
30
20
10
0
#1 Winding
#2 Winding
#3 Winding
Maximum Allowable Current on Coil
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
LOAD ON COIL - AMPERES
CORRECTION EFFECT CURVES
TYPE "T" COILS
DEVIATION vs LOAD

FIGURE 60.

Part III.—MISCELLANEOUS

CHAPTER XIV. COMPASS RECORDS AND REPORTS

132.[1] The following excerpt from the *Compass Record Book*, NBS Form 1101, covers the instructions for the navigating officer regarding the magnetic compasses and the records to be kept on those compasses, and embodies, in essence, the instruction given in the U. S. Navy Regulations regarding the magnetic compasses on board ship.

"The following instructions relative to compass observations and records under cognizance of the Bureau of Ships are issued for the information and guidance of the commanding officers and navigators of the service.

"1. Forms for compass work issued by the Bureau:

(*a*) NBS No. 1101—Compass Record Book.
(*b*) NBS No. 1102—Record of observations and results obtained from swinging ships.
(*c*) NBS No. 1103—Napier diagram for curve of deviations.
(*d*) NBS No. 1104—Deviation tables for all compasses.
(*e*) NBS No. 1105—Deviation table for one compass. (This form for ship's use only)
(*f*) NBS No. 1106—Analysis of deviations.
(*g*) NBS No. 1107—Inventory of compasses.
(*h*) NBS No. 1108—Inventory of navigational instruments.

"2. The 'Compass Record' shall be a complete history of the compasses while on board ship and shall contain copies of all compass reports. It shall be kept by the navigator, who shall sign it and submit it to the commanding officer for his approval on the last day of every quarter. It shall be sent to the Compass Office, U. S. Naval Observatory, when the vessel is put out of commission.

"3. Upon receipt of the compass outfit it shall be carefully inspected. The compasses shall, at the first opportunity, be tested on shore for 'sensibility' and 'time of vibration,' in accordance with the instructions contained on the back of NBS 1107. Com-

[1] For the duration of the war, all the NBS forms should still be maintained on board ship in order to provide a complete history of the compasses, but only NBS Form 1104 (revised November 1943) need be submitted to the Bureau of Ships, except in cases of special request. This form is submitted to the Bureau of Ships in lieu of all other NBS forms after each and every adjustment and compensation. Details of this form and its use are explained in articles 89 and 126, and on the reverse side of the form.

pass material found defective shall be immediately surveyed. An inventory of compasses, form NBS 1107, shall be filled out and sent to the Bureau of Ships on June 30 of each year, and by new ships as soon as practicable after commissioning. Copies of this inventory shall be pasted in the back of this Record Book. An inventory of navigational instruments, form NBS 1108, shall be filled out and sent to the Bureau of Ships on June 30 of each year.

"4. When a vessel is newly commissioned, all the compasses shall be approximately compensated. At the first opportunity after commissioning the ship shall be swung for deviations, as follows: First, with all correctors removed; second, after adjusting, with degaussing coils off; third, with degaussing coils on, and no degaussing compensation coils operating; fourth, with degaussing coils on and compensating coils in adjustment. A complete analysis of the deviations of all compasses installed shall be made, both before and after adjustment, and a complete report forwarded on forms NBS 1102 and NBS 1106 to the Bureau of Ships.

"5. Similar observations and reports shall be made when on or near the magnetic equator, and data for the installation of Flinders bars obtained.

"6. Similar observations and reports shall be made as soon as possible after any considerable change in the magnetic state of the ship which may be caused by any of the following: Flashing, wiping, deperming, major alteration or repair of hull structure or machinery, firing of main-battery guns, lying in the same direction for a period of two or more weeks, or after making a passage during which the same course has been steered for a week or more. In particular, for about thirty days after flashing or wiping, the magnetic state of the vessel will change slowly. It is, therefore, necessary not only to adjust immediately after flashing or wiping, but also to obtain and record deviations at approximate 10-day intervals for thirty days, and to readjust as soon thereafter as possible.

"7. All compasses shall be kept as closely adjusted as practicable. Every effort should be made to swing ship for residual deviations of all compasses at least once in three months. The results, properly recorded on forms NBS 1102 and NBS 1103, shall be entered in the Compass Record. Deviation tables on form NBS 1105 for the standard, battle, maneuvering and auxiliary battle compasses shall be prepared and kept posted near those compasses in such positions as to be accessible to the officer of the deck and other officers concerned in the navigation of the ship. Deviation-tables, on form NBS 1104, for all compasses installed, shall be entered in the Compass Record at the end of every quarter.

"8. Annually, on June 30, all vessels shall submit to the Bureau of Ships Forms NBS 1102 and 1104 completely filled out.

"9. An error in the variation affects the constant coefficient *A* by an amount equal to the error. Once accurately determined (preferably by the method of reciprocal bearings) the *A* should be used as a constant correction to the variation as obtained from the mean of the errors observed on the equidistant compass headings.

"10. Vessels equipped with degaussing coils should be supplied with electromagnetic compass compensating coils. These coils after proper adjustment should not require frequent resetting. Their operation should frequently be checked, however, to make sure that no failure has occurred. It is advisable to observe and record the deviations whenever a routine test of the degaussing coils is made, as well as when a complete swing for deviations is made. Vessels equipped with degaussing coils but no compass compensating coils should swing ship with coils energized at each appreciable change in magnetic latitude."

BUREAU OF SHIPS, *August 1941*. S. M. ROBINSON,
Chief of Bureau.

All the NBS forms listed above must be kept *accurately* and *up to date* in the *Compass Record Book*, and submitted to the Bureau of Ships as required, since these records provide the complete history and are the basis of all calculations concerning the Compasses on board ship.

NBS Form 1103, Napier's Diagram for Plotting the Curve of Deviations, is discussed and illustrated in article 42. NBS Form 1104 (revised November 1943) is discussed and illustrated in articles 89 and 90. NBS Form 1106, Analysis of Deviations, is used in its entirety for analysis of *exact coefficients* when (*a*) the vessel is newly commissioned, (*b*) the vessel is on or near the magnetic equator, and (*c*) the vessel undergoes major structural alterations or repairs. This analysis form is generally used for data taken with all correctors removed in order to determine the exact coefficients for the ship itself, although Flinders bar data can be obtained from such an analysis with correctors in place, provided the correctors are not changed between observations. The purposes of all the other NBS forms are clearly defined in the above excerpt from NBS Form 1101, and additional information for their use is given on each form.

CHAPTER XV. USE OF THE DIP NEEDLE FOR HEELING ADJUSTMENTS

133. As indicated in chapter III, the heeling effects of both the permanent and induced magnetism are corrected by adjusting the position of the *vertical permanent heeling magnet.* This adjustment can be made in either of two ways:

(1) With the ship on an even keel and as close to an east or west magnetic heading as possible, adjust the heeling magnet until a *dip needle* inserted in the compass position is balanced at some predetermined position.

(2) Adjust the heeling magnet while the ship is *rolling* on north and south headings until the oscillations of the compass card have been reduced to an average minimum.

Inasmuch as it is desirable to establish the condition of induction between the heeling magnet and Flinders bar and to reduce the heeling oscillations to a minimum before making the adjustments at sea, the heeling magnet is usually set at dockside by the first method above. Further, it would be difficult to correct the heeling error by rolling at sea before making the other adjustments because uncorrected horizontal errors would cause other oscillations of the compass under rolling conditions. The spheres and Flinders bar produce a certain measure of heeling correction and shielding effect, hence they should be positioned (at least approximately) before making the heeling adjustment by either method.

Since the movement of soft iron correctors tends to change the over-all heeling correction, and since the dip needle method of adjustment is somewhat of an approximation method, such an adjustment should be refined, if possible, by the rolling method after the other phases of adjustment have been completed. This refinement should be made just before taking the residual deviation curve.

134. The fact that the heeling magnet corrects for induced effects as well as permanent effects requires that it be readjusted with radical magnetic latitude changes of the ship. Movement of the heeling magnet, with Flinders bar in the holder, will change the induction effects in the Flinders bar and thus change the compass deviations. (See article 100.) Thus, the navigator is responsible for:

(1) Moving the heeling magnet up or down (invert when necessary) as the ship changes magnetic latitude so as to maintain a good heeling adjustment for all latitudes.

(2) Maintaining a check on his deviations and noting changes resulting from movements of the heeling magnet when Flinders bar is in the holder. Any deviation changes should be either recorded or readjusted by means of the fore-and-aft *B* magnets.

135. To elaborate on the details of the *dip needle method* of adjustment, it is pointed out that there are two types of dip needles: one which assumes the angle of inclination, or dip, for its particular location, and one on which the magnetic torque is balanced by a movable weight. The latter is a nullifying type instrument which renders the final position of the needle more independent of the horizontal component of magnetic fields, and hence is more useful on uncorrected compasses.

For ships which introduce *no shielding* to the earth's field at the compass, the procedure for adjusting the heeling magnet is quite simple. Take the dip needle into a nearby area where there is no local magnetic distraction, level the instrument, and set the weight so as to balance the needle under those conditions of earth's magnetic field. It is preferable to align the instrument such that the north seeking end of the needle is pointing north. Next, level the instrument in the compass position on board ship, place the spheres in their approximate position, and adjust the heeling magnet until the needle assumes the balanced condition. This presumes that all the effects of the ship are canceled, leaving only the effect of the vertical earth's field. The degaussing circuits are secured during this adjustment.

In the case of ships which have *shielding* effects on the earth's field at the compass, as in metal enclosed wheelhouses, the procedure is essentially the same as above, except that the weight on the dip needle should be moved toward the pivot so as to balance against some lesser value of earth's field. The new position of the weight, expressed in centimeters from the pivot, can be approximately determined by multiplying the value of *lambda*, λ, for the compass location by the original distance of the weight from the pivot in centimeters. Should *lambda*, λ, for the compass location be unknown, it may generally be considered as about 0.8 for steering compass locations and 0.9 for standard compass locations. By either method, the weight on the dip needle should be moved in to its new position. Next, level the instrument in the compass position on board ship and adjust the heeling magnet until the needle assumes the balanced condition.

Theoretically, these methods of adjusting the heeling magnet by means of a dip needle should be employed only with the ship on *east or west magnetic headings*, so as to avoid heeling errors resulting from unsymmetrical, fore-and-aft, induced magnetism. If it is impractical to place the ship on such a heading, approximations may be made on any heading and refinements made when convenient.

The dip needle is considered merely as a *balance indicator* when used for correcting the heeling effects of degaussing. As explained in chapters X and XI, the heeling coil currents are adjusted so as to bring the dip needle back to its original balance, and the position of the weight has little meaning.

136. In the final analysis a successful heeling magnet adjustment is one whereby the objectionable oscillations due to rolling of the ship (maximum effects on north and south compass headings) are minimized. Therefore, the *rolling method* is a visual method of adjusting the heeling magnet or checking the accuracy of the last heeling magnet adjustment. Generally, the oscillation effects due to roll on both the north and south compass headings will be the same. However, some unsymmetrical arrangements of fore-and-aft soft iron will introduce different oscillation effects on these two headings; and such effects cannot be entirely eliminated on both headings with one setting of the heeling magnet. Therefore, the heeling magnet is generally set for the *average minimum oscillation condition.*

CHAPTER XVI. USE OF THE HORIZONTAL FORCE INSTRUMENT

137. Occasionally it will be necessary to determine the actual strength of the magnetic field at some compass location. This problem may arise for one of the following reasons:

(1) It may be desired to determine accurately the horizontal shielding factor, λ, for:

(*a*) A complete mathematical analysis.
(*b*) Accurate Flinders bar adjustment.
(c) Accurate heeling adjustment.
(*d*) Calculations on a dockside magnetic adjustment.
(*e*) Determining the best compass location on board ship.

(2) It may be desired to make a dockside magnetic adjustment, and hence determine the existing directive force at the magnetic compass both for its magnitude and direction. (See Kielhorn's, *A Treatise on Compass Compensation*, for details of one heading adjustments.)

Lambda, λ, is the horizontal shielding factor or ratio of the reduced earth's directive force, H', on the compass to the horizontal earth's field, H, as:

$$\lambda=\frac{H'}{H}$$

From this it is apparent that λ may easily be determined for a compass location by making a measurement of the reduced earth's directive force, H'. On a corrected compass, this value H' may be measured with the ship on any heading, since this reduced earth's directive force is the only force acting on the compass. If the compass is not corrected for the ship's magnetism and the deviations are large, H' is determined from the several resultant directive forces observed with equally spaced headings of the ship, as indicated later. Lambda, λ, should be determined for every compass location on every ship, as indicated on form NBS 1104 and NBS 1106.

138. The actual measurement of such magnetic fields may be made by use of a suitable *magnetometer*, or by the use of a *horizontal force instrument*. The magnetometer method is a direct reading method, which needs no calculation. The force instrument is by far the simpler form of equipment, hence the force instrument method is discussed below.

The horizontal force instrument is simply a magnetized needle pivoted in a horizontal plane, much the same as a compass. It will settle in some position which will indicate the direction of the resultant magnetic field. The method used to determine the strength of this resultant field is by comparing it with a known field. If the force needle is started swinging, it will be damped down with a certain *period of oscillation* dependent upon the strength of the magnetic field. The stronger the magnetic field, the shorter the period of time for each cycle of swing; in fact, the ratio is such that the squares of the periods of vibration are inversely proportional to the strengths of the magnetic fields, as:

$$\frac{H'}{H}=\frac{T^2}{T'^2}$$

In the above formula, let H represent the strength of the earth's horizontal field in gauss and T represent the time in seconds for ten cycles of needle vibration in that earth's field. Should it be desired to find the strength of an unknown magnetic field, H', a comparative measurement of time in seconds, T', for 10 cycles of vibration of the same needle in the unknown field will enable calculation of H'.

Since λ is the ratio of two magnetic field strengths, it may be found directly by the inverse ratio of the squares of the periods of vibration for the same horizontal force instrument in the two different magnetic fields by the same formula, without bothering about the values of H and H'.

$$\lambda=\frac{H'}{H}=\frac{T^2}{T'^2}$$

The above may be used on one heading of the ship if the compass deviations are less than 4°.

To obtain the value of lambda, λ, more precisely, and where deviations of the compass exceeds 4°, the following equation should be used:

$$\lambda=\frac{T^2}{4}\left[\frac{\cos d_n}{T^2_n}+\frac{\cos d_e}{T^2_e}+\frac{\cos d_s}{T^2_s}+\frac{\cos d_w}{T^2_w}\right]$$

where:

T is the time period for the field H.

T_n is the time period for the resultant field with ship on a north heading, etc.

$\cos d_n$ is the cos of the deviation on the north heading, etc.

CHAPTER XVII. SLEWING OF SPHERES

139. Figure 19, The Summary of Compass Errors and Adjustments, outlines the use of spheres for correcting all quadrantal errors. It will be observed that spheres are used athwartship to correct plus *D* (easterly) error and fore-and-aft to correct minus *D* (westerly) error. Should the quadrantal deviations be of an *E*, rather than a *D* nature, correction is achieved by placing the spheres on either of the intercardinal axes, as shown. Generally, the *E* error is so small that correction is unnecessary except on compasses which are mounted unsymmetrically with respect to the masses of metal in the ship. However, when *E* error does exist, it is usually in conjunction with

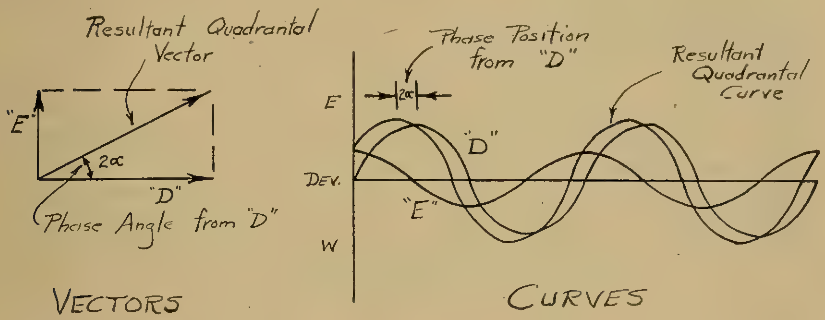


FIGURE 61.—Vector analysis of quadrantal error.

D error, and the typical problem involving *E* error requires a correction for both the *D* and *E* components. Such correction could be achieved by using two sets of spheres on the appropriate axes, but it is more logically made by placing the existing set of spheres on some intermediate axis so as to correct the resultant quadrantal error directly.

Inasmuch as the *D* and *E* coefficients represent two quadrantal sine functions whose phase positions are 90° apart, their resultant effect will also be a quadrantal sine function of larger magnitude, at some intermediate phase position. Since this problem involves the addition of two sine functions, a *vector analysis* is convenient for determining the magnitude and phase position of the resultant quadrantal error.

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In figure 61, 2α is easily calculated from:

$$\tan 2\alpha=\frac{E}{D} \text{ or } 2\alpha=\tan^{-1}\frac{E}{D} \text{ or } \alpha=\tfrac{1}{2}\tan^{-1}\frac{E}{D}$$

This angle, 2α, is the phase position angle of the resultant quadrantal error with respect to the D error, in terms of the quadrantal frequency. It is apparent that this angle indicates the amount of slew necessary for the spheres to correct both the D and E errors; but, since the quadrantal curves experience two cycles of deviation for one cycle of swinging ship, the actual angle to slew the spheres from the D position will be only half this phase position angle. Therefore, α is the angle to slew the spheres from the D axis. If the D and E coefficients are positive, the spheres should be slewed clockwise from the athwartship position, whereas if the D coefficient is positive and the E coefficient is negative, the spheres should be slewed counter-clockwise from the athwartship position.

The resultant amount of quadrantal correction necessary to handle the D and E coefficients directly with the spheres in the slewed position is found by the formula:

$$\text{Resultant quadrantal}=\sqrt{D^2+E^2}$$

This resultant correction is then corrected by moving the spheres in or out on the axis, indicated by α.

140. Figure 33 is a *graphical arrangement* which can be used to quickly solve any vector problem similar to the one described above. It not only solves the angle of slew and the resultant quadrantal error, but indicates the proper direction of slew for any given values of D and E. The solution of a sample problem, using this chart, is presented in article 94.

The need for slewing spheres may be observed on any *single latitude adjustment* by merely determining the coefficients D and E. The same principles of needle induction and latitude effects on quadrantal errors hold true for E error as for D error, as discussed in article 92.

Although the average binnacle does not have movable sphere bracket arms, special E links may be made to allow slewing the spheres to any desired position using the existing bracket arms.

CHAPTER XVIII. SLEWING OF FLINDERS BAR

141. The need for slewing Flinders bar is much more rare than that for slewing spheres. Also, the data necessary for slewing the Flinders bar *cannot be obtained on a single latitude adjustment*, as with the spheres. Slewing the bar to some intermediate position is, in effect, merely utilizing one bar to do the work of two; one forward or aft, and the other port or starboard.

Article 97 explains that a change of the E./W. deviations with changes in latitude indicates the need for Flinders bar forward or aft of the compass; and a change of the N./S. deviations with changes in latitude indicates the need for Flinders bar to port or starboard of the compass.

A change of the B deviations on magnetic E./W. headings is used, as explained in article 97, to determine the proper amount of Flinders bar forward or aft of the compass by calculating the constant c.

If there is a change of the C deviations on magnetic N./S. headings, a similar analysis may be made to determine the proper amount of Flinders bar to port or starboard of the compass by calculating the constant f from:

$$f=\lambda\left[\frac{H_1 \tan C_1-H_2 \tan C_2}{Z_1-Z_2}\right]$$

when

λ=shielding factor (0.8 to 1.0 average).

H_1=earth's field, H, at 1st latitude.

C_1=degrees C deviation at 1st latitude (magnetic headings).

Z_1=earth's field, Z, at 1st latitude.

H_2=earth's field, H, at 2d latitude.

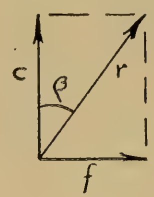
C_2=degrees C deviation at 2d latitude (magnetic headings).

Z_2=earth's field, Z, at 2d latitude.

Any value of this f constant indicates the need for Flinders bar adjustment athwartship of the compass, just as a value of the c constant indicates the need for Flinders bar adjustment forward or aft of the compass. The f constant curve in figure 34 (b) is used for the determination of this Flinders bar length. If f is negative, Flinders bar is required on the starboard side of the binnacle.

142. Should both c and f exist on a ship, the angular position for a Flinders bar to correct the resultant vertical induction effects may be found by:

$$\tan \beta = \frac{f}{c} \text{ or } \beta = \tan^{-1} \frac{f}{c}$$



β is the angle to slew the Flinders bar from the fore-and-aft axis. If c and f are negative, the bar will be slewed clockwise from the forward position; if c is negative and f is positive, the bar will be slewed counterclockwise from the forward position; and if c is positive and f is negative, the bar should be slewed counterclockwise from the aft position.

After so determining the angle to slew the Flinders bar from the fore-and-aft line, the total amount of Flinders bar necessary to correct the resultant vertical induction effects in this position is found by:

$$r = \sqrt{c^2 + f^2}$$

The constant r is then used on the c or f constant curve in figure 34 (b) to determine the total amount of Flinders bar necessary in the slewed position.

CHAPTER XIX. REMOTE READING COMPASSES

143. *Remote reading magnetic compass systems* have been introduced principally because of the desire to improve the magnetic location of compass elements. Such improvement is particularly important on small craft because of adjacent machinery and magnetic cargo. Reference is made to the Bureau of Ship's Manual of Engineering Instructions, 1943, Chapter 24, Part 2, paragraphs 24–27:

> "Auxiliary remote reading magnetic compass systems are supplied by the Bureau for certain surface craft. These compasses fall into three classes:
>
> (*a*) Magnetic compasses, with direct electrical transmission to repeaters.
>
> (*b*) Magnetically controlled directional gyros with repeater system.
>
> (*c*) Gyro-stabilized induction compasses with repeater system.
>
> "Complete units will be supplied by the Bureau of Ships. Instructions for installation, operation, and maintenance will accompany each instrument. The Engineer Officer shall be responsible for the care and maintenance of this equipment aboard ship."

The Magnesyn Compass is an example of class (*a*) above; and, once located in some suitable position, is compensated in a manner similar to the conventional magnetic compass. This compass is used extensively on landing craft and on certain selected combatant vessels. On the latter, the Magnesyn compass system is fitted with compensating coils for degaussing. The type coil installation may vary, but should be readily understood upon reference to the installation and maintenance manuals prepared for that particular type coil.

The slave gyro remote indicating compass is an example of class (*b*) above. In this compass a directional gyro is slaved; that is, made to precess to the magnetic meridian by a magnetic compass. The repeaters are driven by a selsyn system mechanically connected to the directional gyro. The magnetic compass element of the slave can be corrected for normal coefficients and, under severe conditions, can be corrected for coefficients D and E. Error due to rolling, but not list, is balanced out by the stability of the directional gyro; whereas, the error due to constant list will introduce deviations on north and south courses.

The Fluxgate induction compass is an example of class (*c*) above. The compensation of this instrument is purely mechanical and is not to be compared with compensation of the conventional magnetic compass. This compass is not discussed specifically in this publication inasmuch as its use is confined to special vessels where specifically trained personnel are available for maintenance and service.

Requests for additional information should be made to the Bureau of Ships, Navy Department, Washington, D. C.

APPENDIX

SUGGESTED COURSE OF STUDY FOR MAGNETIC COMPASS ADJUSTMENT AND COMPENSATION

A. **Outline.**
B. **Bibliography.**
C. **Problems.**
D. **Answers to Problems.**

APPENDIX A

OUTLINE FOR COURSE OF STUDY

I. General outline of magnetism. (See chap. II):
- A. Magnetic lines of force. Magnetic poles.
  - 1. Opposite poles attract. Like poles repel.
- B. Magnetism:
  - 1. Permanent and subpermanent.
    - (a) Changes due to deperming or vibration.
  - 2. Induced:
    - (a) Varies with field intensity, alignment, and physical dimensions.
- C. Earth's Magnetism:
  - 1. Earth's magnetic poles.
    - (a) Red and blue, north and south, plus and minus.
  - 2. Earth's magnetic field.
    - (a) Variation in direction from true north.
    - (b) Different vertical and horizontal components.
    - (c) Charts of vertical intensity, horizontal intensity, angle of dip, variation.
    - (d) Annual changes, anomalies, etc.
- D. Resultant field (vector problem):
  - 1. Compass card—needle arrays.
  - 2. Compass deviation.
- E. Inverse square law.
- F. Shielding.

II. Theory of magnetic compass adjustment. (See chap. III):
- A. Permanent magnetic effects:
  - 1. Vertical component, *H*—oscillating effect when rolling.
    - (a) Varies with latitude.
  - 2. Longitudinal component, *B*—semicircular deviation.
    - (a) Varies with latitude.
  - 3. Athwartship component, *C*—semicircular deviation.
    - (a) Varies with latitude.
- B. Correction for permanent magnetic effects—Use permanent magnet correctors:
  - 1. *H* effect—vertical heeling magnet.
  - 2. *B* effect—fore-and-aft *B* magnets.
  - 3. *C* effect—athwartship *C* magnets.
- C. Induced magnetic effects:
  - 1. Vertical component at compass—heeling effect.
    - (a) Varies with latitude.
  - 2. Vertical resultant—semicircular deviation.
    - (a) Varies with latitude.
  - 3. Symmetrical distribution of horizontal soft iron, *D*—quadrantal deviation, maximum on intercardinal headings.
    - (a) Does not vary with latitude.
  - 4. Unsymmetrical distribution of horizontal soft iron, *E*—quadrantal deviation, maximum on cardinal headings.
    - (a) Does not vary with latitude.

II. Theory of magnetic compass adjustment—Continued.
  C. Induced magnetic effects—Continued.
    5. Unsymmetrical distribution of horizontal soft iron, *A*—constant deviation on all headings.
      (*a*) Does not vary with latitude.
  D. Correction for induced magnetic effects—Use soft iron correctors.
    1. Vertical component—heeling magnet (exception).
    2. Vertical resultant—Flinders bar.
    3. Quadrantal deviation—spheres.
  E. Constant error, *A*:
    1. Human error in calculations.
    2. Physical misalignments.
    3. Magnetic effects.
  F. Interaction of magnetic correctors:
    1. Heeling magnet and Flinders bar.
    2. Magnetized spheres or Flinders bar.
    3. Compass needle induction in spheres.
    4. Flinders bar creates plus *D* error.
    5. Slewing bar creates *E* error.
    6. Flinders bar and fore-and-aft *B* magnets.
    7. Spheres and permanent magnets.
  G. Residual Deviation Curve:
    1. Specify corrector positions.
    2. Possible changes.
      (*a*) Improper Flinders bar adjustment.
      (*b*) Change in directive force.
      (*c*) Heeling with latitude.
      (*d*) Deperming.
      (*e*) Gyro repeater, doors, guns, etc.

III. Practice session:
  A. Become familiar with different binnacles and corrector arrangements.
  B. Observe the effects of different magnets, spheres, and Flinders bar correctors while the ship is on different compass headings.
  C. Check spheres and Flinders bar for magnetization.

IV. Theory of magnetic compensation (See ch. XI):
  A. Degaussing coil effects—Electro-magnetic effects:
    1. Type degaussing coils.
    2. Ampere-turn rating.
    3. Location of compass.
    4. Steel distribution.
  B. Correction for degaussing coil effects—Use coils:
    1. Types of compass compensating coils.
    2. Vector components.
  C. Connection to degaussing systems:
    1. Must provide a voltage which is—
      (*a*) Proportional to degaussing current.
      (*b*) Reversible with degaussing current.
  D. Control boxes:
    1. Potentiometer circuit with coarse and fine resistor adjustments.
  E. Relation of compass compensation to compass adjustment:
    1. Flinders bar coil utilizes Flinders bar as iron core.
    2. Sphere coils are dependent upon size and position of quadrantal spheres.

IV. Theory of magnetic compensation (See ch. XI)—Continued.
  E. Relation of compass compensation to compass adjustment—Continued.
    3. Degaussing deviation curve is superimposed upon normal curve.
  F. Secure degaussing by reversal, if necessary.
  G. Dockside compensation:
    1. Deflection of compass needles.
    2. Dockside interferences.
  H. Final compensation. Refinement of dockside compensation at sea.
  I. Deviation curves:
    1. Undegaussed condition.
    2. Degaussed condition.

V. Ship's heading. (See ch. V):
  A. Relation between true, magnetic, and compass heading:
    1. Variation and deviation.
    2. Compass heading for adjustment.
    3. Magnetic heading for adjustment.
    4. Napier's diagram for conversion between compass and magnetic heading.
    5. Rules for conversion.
      (*a*) When correcting, apply sign property (+E, —W).
      (*b*) "Compass least, deviation east." "Compass best, deviation west."
  B. Charts and instruments:
    1. Parallel rules, compass roses, variation, annual change, etc.
    2. Use of pelorus.
    3. Use of azimuth circle.
    4. Use of gyro.
  C. Methods of taking bearings:
    1. Azimuths.
    2. Gyro.
    3. Distant object.
    4. Ranges.
    5. Reciprocal bearings.

VI. Problem session:
  A. Practice problems with variation and deviation.
  B. Practice problems using gyro, pelorus, and azimuth circle.
  C. Study of charts, choosing ranges, distant objects.

VII. Practice session:
  A. Become familiar with different peloruses and azimuth instruments.
  B. Obtain the magnetic bearing of some distant object from your binnacle by averaging compass bearings found with ship on eight different compass headings.
  C. Determine two deviation curves for your ship on eight headings—one each for compass and magnetic headings.
  D. Plot deviations as against both compass and magnetic headings. Study differences.

VIII. Description of the approximate coefficients of deviation and their estimation (see ch. IV):
  A. Coefficients *A*, *B*, *C*, *D*, and *E*.
  B. Estimate the coefficients for the deviation curve obtained in practice session, using compass headings.
  C. Other practice problems.

IX. Practical procedure for adjusting different effects (see ch. VII):
- A. Curve analysis.
- B. Simple one-swing method.

X. Practice session:
- A. Adjust your compass, and hand in the original and final deviation curves (plotted against both compass and magnetic heading) as well as the estimated coefficients and sequence of your procedure. (Note that deviations are same for compass and magnetic headings, after adjustment.)

XI. Calculation of sun's azimuths (see ch. VI):
- A. Time:
  1. Local apparent time (L. A. T.).
  2. Equation of time (Eq. T.).
  3. Longitude correction.
  4. Time zones.
  5. Other time nomenclature.
     - (*a*) G. C. T.
     - (*b*) G. A. T.
     - (*c*) Std. T.
     - (*d*) L. C. T.
  6. Hour angle (H. A.), Meridian angle (*t*).
- B. Azimuth tables (H. O. 71 and H. O. 214):
  1. Declination, contrary name with latitude.
  2. Declination, same name with latitude.
  3. Latitude, declination, L. A. T.
  4. Rules for a. m. and p. m., north and south latitudes.
- C. Simplified use of L. A. T. watch and prepared azimuth tables.
- D. Prepare the proper azimuth table for the ensuing practice session.

XII. Practice session:
- A. Complete adjustment on a binnacle, using the sun's azimuths.
- B. Complete adjustment on a binnacle, using a bearing on a distant object. (Hand in deviation curves, procedure, and estimated coefficients.)

XIII. Complete shipboard procedure for making a magnetic adjustment (see ch. I and VII):
- A. Use of dip needle (ch. XV).
- B. Physical check of equipment (ch. I).

XIV. Demonstration of degaussing coil compensation.

XV. Complete shipboard procedure for making a compass coil compensation. (See ch. X.)

XVI. Miscellaneous problems:
- A. Frozen compasses—Sluggish and unsteady (art. 33).
- B. Corrector effects (ch. VIII).
- C. Slewing spheres (ch. XVII).
- D. Flinders bar adjustment (ch. VIII).
- E. Gaussin error (art. 105).
- F. Transients (ch. IX).
- G. Remote reading compasses (ch. XIX).
- H. Slewing Flinders bar (ch. XVIII).
- I. One heading adjustment (Kielhorn).
- J. Complete mathematical analysis (Kielhorn and British Admiralty Manual).
- K. Use of the horizontal force instrument (ch. XVI).

XVII. Final examination.

APPENDIX B

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2. Navigation and Nautical Astronomy, by Commander Benjamin Dutton, United States Navy.
3. Admiralty Navigation Manual, Vols. I, II, and III, by British Admiralty.
4. Navigation and Compass Deviations, by Commander W. C. P. Muir, United States Navy.
5. Wrinkles in Practical Navigation, by S. T. S. Lecky.
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7. American Practical Navigator (H. O. No. 9), by Nathaniel Bowditch.

APPENDIX C

PROBLEMS

PROBLEM 1

A. Analyze the following deviation curves for the approximate coefficients. Assuming that these are actual deviation curves, show how this analysis could be utilized to make necessary corrections on the appropriate headings, one at a time. Show anticipated residuals on all headings, after each correction has been made.

(1) Standard compass:

000°	6. 0 E.
045°	1. 5 E.
090°	8. 0 W.
135°	10. 5 W.
180°	2. 0 W.
225°	4. 5 E.
270°	4. 0 E.
315°	4. 5 E.

(2) Steering compass:

000°	8. 0 W.
045°	2. 5 W.
090°	11. 0 E.
135°	16. 0 E.
180°	4. 0 E.
225°	4. 5 W.
270°	3. 0 W.
315°	3. 5 W.

B. Assume that the standard binnacle has no correctors on it. State what correctors you would employ and how you would place them in order to remove the coefficients of deviation.

C. Assume that on the steering binnacle you have correctors as follows:

Fore-and-aft magnets, red ends aft.
Athwartships magnets, red ends port.
No Flinders bar.
2–7″ spheres at 12.5″.

State how you would adjust the existing correctors to remove these coefficients of deviation.

D. State what type of ship's magnetism would cause each type of deviation represented by the coefficients of the deviation curve on the steering compass.

PROBLEM 2

[Fill in the blanks]

Standard compass head	Deviation	Gyro error	Variation	Gyro head	Magnetic head	Steering compass head	Deviation	True head
002	3 W.	1 E.	------	350	------	005	------	------
268	------	------	13 E.	284	------	------	3 W.	282
------	2 E.	2 W.	------	------	181	175	------	175
------	4 W.	------	11 W.	088	------	095	6 W.	------
010	------	3 W.	7 E.	------	------	000	------	006

Gyro error	Steering compass head	Deviation	True head	Standard compass head	Deviation	Variation	Magnetic head	Gyro head
------	------	3 E.	000	004	4 W.	------	------	004
2 W.	278	------	------	268	------	7 E.	------	280
2 E.	------	5 W.	171	------	0	------	182	------
0	090	------	------	089	1 W.	------	------	083
------	000	------	------	------	0	10 W.	357	345

Variation	Magnetic head	Gyro head	Standard compass head	Deviation	True head	Steering compass head	Deviation	Gyro error
11½ E.	------	010½	359½	------	------	------	3½ W.	2½ E.
7½ W.	------	264	271½	½ E.	------	268½	------	------
------	181	------	183½	------	195½	------	2½ E.	1½ W.
5½ E.	------	007½	------	2½ W	------	001	1½ E.	------
------	092½	092½	093	------	082½	089½	------	------

PROBLEM 3

A		C	
L. A. T	0900.	L. A. T	1500.
Latitude	38. 0° S.	Latitude	36. 3° S.
Declination	15. 0° N.	Declination	7. 0° S.
Variation	11. 0° W.	Variation	3. 5° W.
True azimuth		True azimuth	
Magnetic azimuth		Magnetic azimuth	

B		D	
L. A. T	1400.	L. A. T	0953.
Latitude	39. 0° N.	Latitude	37. 7° N.
Declination	21. 5° S.	Declination	17. 6° N.
Variation	9. 0° E.	Variation	13. 7° E.
True azimuth		True azimuth	
Magnetic azimuth		Magnetic azimuth	

PROBLEM 4

1. Magnetic heading differs from true heading by—
   (*a*) Compass error.
   (*b*) Variation.
   (*c*) Deviation.
2. The Flinders bar is used to correct for—
   (*a*) Permanent fore-and-aft magnetic fields.
   (*b*) Induced magnetism in horizontal soft iron.
   (*c*) Induced magnetism in vertical soft iron.
3. Deperming is employed—
   (*a*) To reduce the permanent magnetism of the ship.
   (*b*) To reduce the magnetism in the soft iron of the ship.
   (*c*) To make for better compass adjustment.
4. Spheres and Flinders bar should be annealed—
   (*a*) After deperming.
   (*b*) After crossing the equator.
   (*c*) When they become magnetized.
5. The standard compass is so called because—
   (*a*) It uses standard size magnets and spheres.
   (*b*) It is usually in the best location and should be used as a standard reference for other compasses.
   (*c*) It has a standard size card.
6. Shielding on a ship is—
   (*a*) The effect of the compass needles on the spheres.
   (*b*) The effect of the metal around the compass on the magnetic lines of force.
   (*c*) Putting the top on the compass to protect it from the weather.
7. If the deviations on a compass were 8° easterly on north and south, and 8° westerly on east and west—
   (*a*) The compass needs larger spheres.
   (*b*) The spheres need slewing.
   (*c*) The compass needs less Flinders bar.
8. A ship having a deviation curve indicating no *E* error at the equator and whose deviation curve shows considerable *E* error on arriving at New York has—
   (*a*) Improper data.

(b) Improper sphere correction.
(c) Improper Flinders bar correction.

9. Should the value of *D* change with latitude it is because—
(a) Spheres are magnetized.
(b) Induction in the spheres by the compass needles.
(c) Spheres are too far out from the compass and have no effect.

10. If the Flinders bar length is doubled—
(a) It must be inverted.
(b) It will necessitate changing the position of the heeling magnet.
(c) Sphere correction should also be revised.

PROBLEM 5

True—False. (Also give one sentence comments.)

1. A magnetically frozen compass reading 090° for all headings of the ship would require fore-and-aft magnets in order to free it.
2. The position of the heeling magnet, although once adjusted, should be changed as required with latitude changes.
3. Axiomatically enough, large spheres are always used on large ships and small spheres on small ships.
4. Although the degaussing compass compensating coils were not changed, if the compass is readjusted magnetically, a new deviation curve must be taken for both degaussed and undegaussed conditions of the ship.
5. After a ship is depermed it will require more Flinders bar.
6. If there is a Flinders bar in the binnacle a change in the heeling magnet will probably change the error on an east heading.
7. Heeling errors, due to roll, are most noticeable on north and south headings.
8. A Napier's diagram is a device for determining the proper length of Flinders bar.
9. When swinging for a degaussing deviation curve, the degaussing coils must all be energized at full value.
10. If degaussing throws a compass off over 90° it cannot be corrected.
11. If, upon securing the degaussing directly, the compass does not return to normal, the coils must be recompensated.
12. It is good practice to delay adjustment until three or four days after deperming, if possible.
13. A ship travelling on a north heading while practicing gunnery should expect to acquire a westerly *B* error.
14. If a compass has the same westerly error on all four intercardinal headings it should have larger spheres.
15. If a heeling coil adjustment for compass compensation is changed the *B* coil correction will probably have to be corrected again.
16. Flinders bar corrects for induced effects in horizontal soft iron due to changes with latitude.
17. A ship built on an east-west heading will probably have its maximum deviations on north and south headings.
18. A compass with westerly deviation on an east heading will require magnets athwartship, red to port.
19. In making a dockside setting of the compass compensating coils the degaussing coils should be energized at maximum operating currents to insure greatest accuracy of adjustment.

20. In magnetic adjustments it is best to place fewer magnets very close to the compass rather than more magnets farther away from the compass.

21. After deperming, a ship will need smaller spheres.

22. Heeling errors, due to pitch, are most noticeable on east and west headings.

23. The *D* error, once corrected, should remain corrected regardless of changes in magnetic latitude or changes of *B* or *C* correctors.

24. The navigator on crossing the equator from south latitude to north latitude must invert the Flinders bar so as to have the blue end up in north latitudes.

25. If deviation due to magnetic *A* is present it will change as the ship progresses toward the magnetic equator because the directive force changes.

26. On a properly adjusted compass the heeling magnet is the only corrector which corrects for both permanent and induced magnetism.

27. With all types of compass compensating coil installations, if the amount of Flinders bar is changed the compass compensating coils will have to be recompensated.

28. A ship traveling on an east heading while practicing gunnery should expect to acquire an easterly *B* error.

29. If a ship adjusted at New York goes to the magnetic equator and acquires large deviations on east and west headings only, this indicates a need for adjustment of the fore-and-aft magnets at that locality.

PROBLEM 6

The U. S. S. *Whip* was adjusted at New York, N. Y., and recorded the following table of deviations for compass headings:

000°	1 E.	180°	1 E.
045°	3 E.	225°	1 W.
090°	1 E.	270°	1 W.
135°	2 E.	315°	0

The U. S. S. *Whip* had fore-and-aft magnets red aft and athwartships magnets red port, two 7 inch spheres athwartships at 15 inches and 6 inches of Flinders bar forward of the binnacle.

On arrival at the Panama Canal Zone the U. S. S. *Whip* was swung for a deviation curve with the same corrector conditions and the following table of deviations on compass headings was recorded:

000°	2 E.	180°	2 E.
045°	7 E.	225°	7 W.
090°	10 E.	270°	8 W.
135°	5 E.	315°	5 W.

Analyze the above deviation curves and determine what coefficients should be corrected at Panama. State what correctors you would adjust to correct these coefficients; and, whenever possible, give the magnitude and direction of these adjustments.

639720—45——10

APPENDIX D

ANSWERS TO PROBLEMS

ANSWER TO PROBLEM 1

(A).

(1) Standard compass:

$A=0.0°$

$B=6.0°$ W.

$C=4.0°$ E.

$D=3.0°$ E.

$E=2.0°$ E.

(2) Steering compass.

$A=1.2°$ E.

$B=7.0°$ E.

$C=6.0°$ W.

$D=4.9°$ W.

$E=3.0°$ W.

(1) Standard compass:

Heading	Original deviation	After *B* correction	After *C* correction	After *D* correction	After *E* correction
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	6.0 E	6.0 E	2.0 E	2.0 E	0.0
045	1.5 E	5.7 E	2.9 E	0.1 W	0.1 W
090	8.0 W	2.0 W	2.0 W	2.0 W	0.0
135	10.5 W	6.3 W	3.5 W	0.5 W	0.5 W
180	2.0 W	2.0 W	2.0 E	2.0 E	0.0
225	4.5 E	0.3 E	3.1 E	0.1 E	0.1 E
270	4.0 E	2.0 W	2.0 W	2.0 W	0.0
315	4.5 E	0.3 E	2.5 W	0.5 E	0.5 E

(2) Steering compass:

Heading	Original Deviation	After *A* correction	After *B* correction	After *C* correction	After *D* correction	After *E* correction
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	8.0 W	9.2 W	9.2 W	3.2 W	3.2 W	0.2 W
045	2.5 W	3.7 W	8.6 W	4.4 W	0.5 E	0.5 E
090	11.0 E	9.8 E	2.8 E	2.8 E	2.8 E	0.2 W
135	16.0 E	14.8 E	9.9 E	5.7 E	0.8 E	0.8 E
180	4.0 E	2.8 E	2.8 E	3.2 W	3.2 W	0.2 W
225	4.5 W	5.7 W	0.8 W	5.0 W	0.1 W	0.1 W
270	3.0 W	4.2 W	2.8 E	2.8 E	2.8 E	0.2 W
315	3.5 W	4.7 W	0.2 E	4.4 E	0.5 W	0.5 W

(B) Place fore-and-aft magnets red ends aft. Place athwartships magnets red ends to starboard. To correct *D* and *E* place spheres on athwartships axis and slew about 17° clockwise. Move sphere to 15″ postion. (See fig. 31, 33, and ch. XVII.)

(C) Slew binnacle 1.2° clockwise. Lower the fore-and-aft magnets to remove 7° E. deviation. Raise the athwartships magnets to remove 6° W. deviation. Slew spheres about 28° counter-clockwise from athwartship axis and move out to 15″ to remove *D* of 4.9° W. and *E* of 3° W. (See figs. 31, 33, and ch. XVII.) It must be remembered that in this problem the spheres at their existing positions are correcting about 7° E. *D* error, thus making the total *D* about 2° E. and *E* about 3° W. This indicates slewing 28° counter-clockwise and a resultant quadrantal error of about 3.5°, which requires the 7″ spheres at the 15″ position.

(D) (See summary of compass errors and adjustment) figure 19.

ANSWERS TO PROBLEM 2

[*Indicates answers]

Standard compass head	Deviation	Gyro error	Variation	Gyro head	Magnetic head	Steering compass head	Deviation	True head
002	3 W.	1 E.	*8 W.	350	*359	005	*6 W.	*351
268	*1 E.	*2 W.	13 E.	284	*269	*272	3 W.	282
*179	2 E.	2 W.	*6 W.	*177	181	175	*6 E.	175
*093	4 W.	*10 W.	11 W.	088	*089	095	6 W.	*078
010	*11 W.	3 W.	7 E.	*009	*359	000	*1 W.	006

Gyro error	Steering compass head	Deviation	True head	Standard compass head	Deviation	Variation	Magnetic head	Gyro head
*4 W.	*357	3 E.	000	004	4 W	*0	*000	004
2 W.	278	*7 W.	*278	268	*3 E.	7 E.	*271	280
2 E.	*187	5 W.	171	*182	0	*11 W.	182	*169
0	090	*2 W.	*083	089	1 W.	*5 W.	*088	083
*2 E.	000	*3 W.	*347	*357	0	10 W.	357	345

Variation	Magnetic head	Gyro head	Standard compass head	Deviation	True head	Steering compass head	Deviation	Gyro error
11½ E.	*001½	010½	359½	*2 E.	*013	*005	3½ W.	2½ E.
7½ W.	*272	264	271½	½ E.	*264½	268½	*3½ E.	*½ E.
*14½ E.	181	*197	183½	*2½ W.	195½	*178½	2½ E.	1½ W.
5½ E.	*002½	007½	*005	2½ W.	*008	001	1½ E.	*½ E.
*10 W.	092½	092½	093	*½ W.	082½	089½	*3 E.	*10 W.

ANSWERS TO PROBLEM 3

(A) 47°34′ (47.6°) true.
58°34′ (58.6°) magnetic.

(B) 210°26′ (210.4°) true.
201°26′ (201.4°) magnetic.

(C) 294°19.5′ (294.3°) true.
297°49.5′ (297.8°) magnetic.

(D) 117°04′ (117.1°) true.
103°22′ (103.4°) magnetic.

ANSWERS TO PROBLEM 4

1. (*b*).
2. (*c*).
3. (*a*).
4. (*c*).
5. (*b*).
6. (*b*).
7. (*b*).
8. (*a*).
9. (*b*).
10. (*c*).

ANSWERS TO PROBLEM 5

Answers	*Comment*
(1) False.	The red end of the needle is attracted to the port side of the ship and the compass will need athwartship magnets red to port to unfreeze it.
(2) True.	The heeling magnet corrects, in addition to the permanent vertical magnetism of the ship, induced vertical magnetism which changes with latitude.
(3) False.	There is no correlation between the size of the ship and the amount of horizontal soft iron in the vicinity of the compass.

Answers		*Comment*
(4)	True.	Changing the correctors for the magnetic adjustment will necessitate changing the degaussing compensation and a new curve must be taken for both. Also, the normal curve is the basis of the degaussing curve.
(5)	False.	Deperming does not affect the induced magnetism of a ship.
(6)	True.	Induction in the Flinders bar from the heeling magnet will change as the heeling magnet is raised or lowered.
(7)	True.	The errors introduced by roll on north or south headings will be at right angles to the earth's field and thus oscillations will be maximum on those headings.
(8)	False.	A Napier's diagram is used to obtain magnetic headings from compass headings and vice versa.
(9)	False.	When swinging for the degaussing deviation curve the coils should be set for the actual values as indicated by the range data.
(10)	False.	The coil polarity should be reversed and the regular procedure followed.
(11)	False.	Secure degaussing by reversals to eliminate the residual effect.
(12)	True.	Deperming effects decay very rapidly the first few days, and it is best to let the ship approach a stable state of magnetization before adjusting.
(13)	True.	A red pole would be set up in the bow and this will cause a westerly deviation on east and an easterly deviation on west.
(14)	False.	The same westerly error on all intercardinal headings does not represent *D* error, hence do not use larger spheres.
(15)	True.	Due to the change in the heeling coil current, the induction in the Flinders bar will change and the (B) coil will have to be readjusted.
(16)	False.	Flinders bar corrects for induced effects in vertical soft iron.
(17)	True.	The poles of the ship would probably be in the port and starboard sides of the ship and this would give maximum deviations with the ship on north and south courses.
(18)	False.	Magnets should be fore-and-aft to correct *B* error.
(19)	True.	It is best to magnify the error at dockside in order to get finer adjustment.
(20)	False.	More magnets further away will give a more symmetrical field at the compass.
(21)	False.	Deperming removes only the permanent magnetism of the ship.
(22)	True.	The errors introduced by pitch on east or west will be at right angles to the earth's field and thus will be maximum on those headings.
(23)	False.	Sphere correction effects are not constant for all latitudes because of compass needle induction. Further, the Flinder bar, as a *B* corrector, changes *D* errors.
(24)	False.	The Flinders bar will have a blue end induced in the top after crossing the magnetic equator to north latitude.
(25)	False.	Deviation will not change because the deviating force from horizontal induction varies with the horizontal earth's field, the same as the directive force.
(26)	True.	The heeling magnet compensates for vertical permanent and vertical induced effects.

(27) True. Induction in the Flinders bar from the degaussing coil fields will change as the Flinders bar is changed, and will therefore change the errors from degaussing. Naturally, any compensating coil installation should be recompensated with change in the Flinders bar length.

(28) False. The ship should expect an easterly *C* error.

(29) True. At the equator the fore-and-aft magnets are adjusted. However, the Flinders bar must also be adjusted either at the equator or on the return trip to New York. (See ch. VIII.)

ANSWERS TO PROBLEM 6

The deviation curve recorded at New York contained the following coefficients:

$A=0.8°$ E. $\quad D=0.0°$
$B=1.0°$ E. $\quad E=0.5°$ E.
$C=0.0°$

The deviation curve recorded at the Panama Canal Zone contained the following coefficients:

$A=0.8°$ E. $\quad D=0.0°$
$B=9.0°$ E. $\quad E=0.5°$ E.
$C=0.0°$

It will be noted that the only coefficient which changed during the voyage from New York to the Canal Zone was the *B* coefficient—a change of 8° easterly. Should an examination of the ship's history show that nothing had been done on this voyage to change the permanent magnetism of the ship, then the change in the *B* coefficient may reasonably be attributed to improper Flinders bar correction. The necessary amount of Flinders bar is calculated by means of the formula given in chapter VIII. The *B* coefficients of deviation used in this formula are taken from the data obtained on magnetic headings. Inasmuch as the data available in this problem was taken on compass headings the Napier's diagram must be used to convert to the equivalent *B* deviations on magnetic headings. In this problem the difference between the deviations on E./W. compass headings and the deviations on E./W. magnetic headings proves to be negligible.

It is pointed out that none of the correctors, permanent or induced (including the heeling magnet), should be moved while on the voyage from New York to the Canal Zone or the results for purposes of Flinders bar calculation will not be reliable. For a further discussion of the conditions under which to take deviation curves for determining the length of Flinders bar, see chapter VIII.

Assume λ (shielding) to be 0.8 of unity.

$H_1=0.170$ (at New York).
$Z_1=0.539$ (at New York).
$B_1=1.0°$ E. (*B* coefficient at New York).
$H_2=0.311$ (at Canal Zone).
$Z_2=0.260$ (at Canal Zone).
$B_2=9.0°$ E (*B* coefficient at Canal Zone).

$$c=0.8\left[\frac{0.170\times0.0175-0.311\times0.1584}{0.539-0.260}\right]$$

$$c=0.8\left[\frac{0.0030-0.0493}{0.279}\right]$$

$$c=0.8\left[\frac{-0.0463}{0.279}\right]$$

$$c=-\left[\frac{0.0370}{0.279}\right]=-0.133$$

Referring to figure 34 (b) it is noted that the existing Flinders bar (6″ forward) represents a *c* correction of (—0.01). The total *c* of the ship, then, which requires correction is (−0.01)+(—0.133) or (—0.143). Figure 34 (b) shows that *c* of (−0.143) requires 24″ of Flinders bar forward of the binnacle.

Figure 32 shows that the existing 6″ of Flinders bar is creating 1° of +*D* error. 24″ of Flinders bar from figure 32 will create 3.5° of +*D*. The spheres must therefore be moved in to correct 2.5° additional + *D* error after placing the 24″ of bar on the binnacle. Referring to figure 31 it is noted that in order to correct for this 2.5° of +*D* the existing spheres must be moved in from the present 15″ position to approximately 13″.

In summary, the procedure at Canal Zone is as follows:

1. Add 18″ more Flinders bar to make a total of 24″.
2. Move spheres in to 13″.
3. Adjust the heeling magnet, if necessary.
4. Swing ship and remove all remaining cardinal heading deviations with the fore-and-aft and athwartship magnets and check sphere correction.
5. If compass is equipped with compensating coils, the adjustment of current in these coils should be refined because of the movement of soft iron correctors. In this case, care should be exercised in energizing the degaussing coils because of the increased amount of Flinders bar and, if Type "B" coils are installed, it would be well to remove the jumpers in the Flinders bar circuits.
6. Swing ship for the *two* customary deviation curves for degaussed and undegaussed conditions.

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